Report MDC E0020
1 October 1969
REVISED 6 OCTOBER 1969

Final Oral Briefing

Optimized Cost/Performance Design Methodology

CONTRACT NAS 2-5022

MCDONNELL DOUGLAS ASTRONAUTICS COMPANY
EASTERN DIVISION
Saint Louis, Missouri 63166 (314) 232-0232

MCDONNELL DOUGLAS
CORPORATION

LIST OF PAGES

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MAC 231X (REV 23 JUN 61)

OBJECTIVES

The study objectives can be summarized in these three items.

OBJECTIVES

- DEVELOP A COST MODEL
- EXERCISE THE COST MODEL
- IDENTIFY CRITICAL PROBLEMS AND KEY TECHNOLOGY REQUIREMENTS

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STUDY CONSTRAINTS

Many ground rules and assumptions were established and are detailed in the study reports. Those with the most important implications are summarized here. Special significance is attached to the second item listed because, as a result, the launch vehicle requirements and costs were treated parametrically.

STUDY CONSTRAINTS

- GEMINI & SATURN S-IVB ARE THE PRIMARY SOURCES OF HISTORICAL COST DATA
- EMPHASIS ON SPACECRAFT FOR MANNED LOGISTICS MISSION
- SYSTEM ANALYSIS TO BE PARAMETRIC

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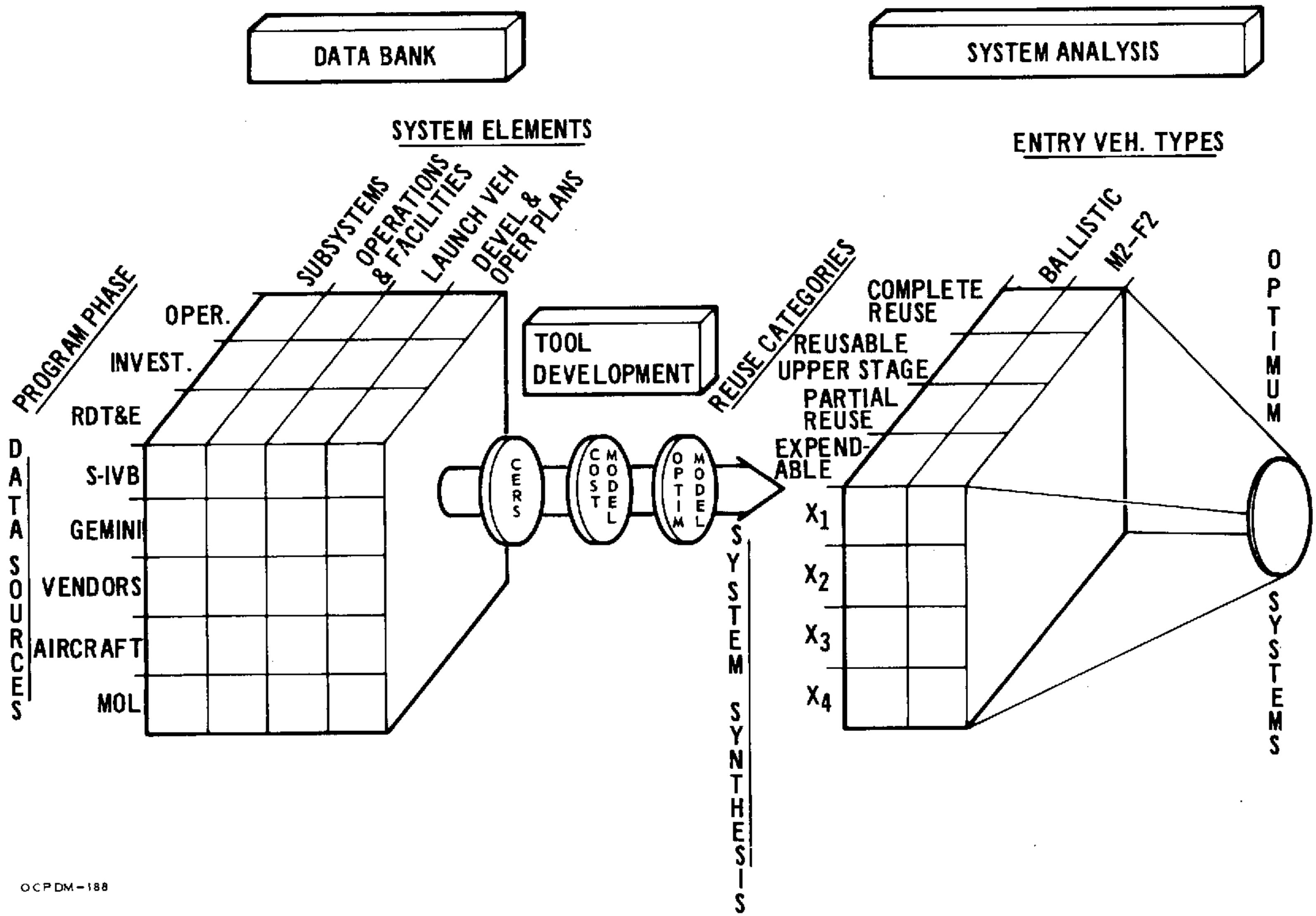
ADVANCED SPACECRAFT COST ANALYSIS

The complete study approach is summarized as shown, and consisted of three major types of work: 1) preparation of a data bank that would contain both cost data and design data; 2) preparation of an automated tool that includes parametric design estimating relationships as well as cost estimating relationships, and 3) analysis of total systems to derive cost trends.

ADVANCED SPACECRAFT COST ANALYSIS



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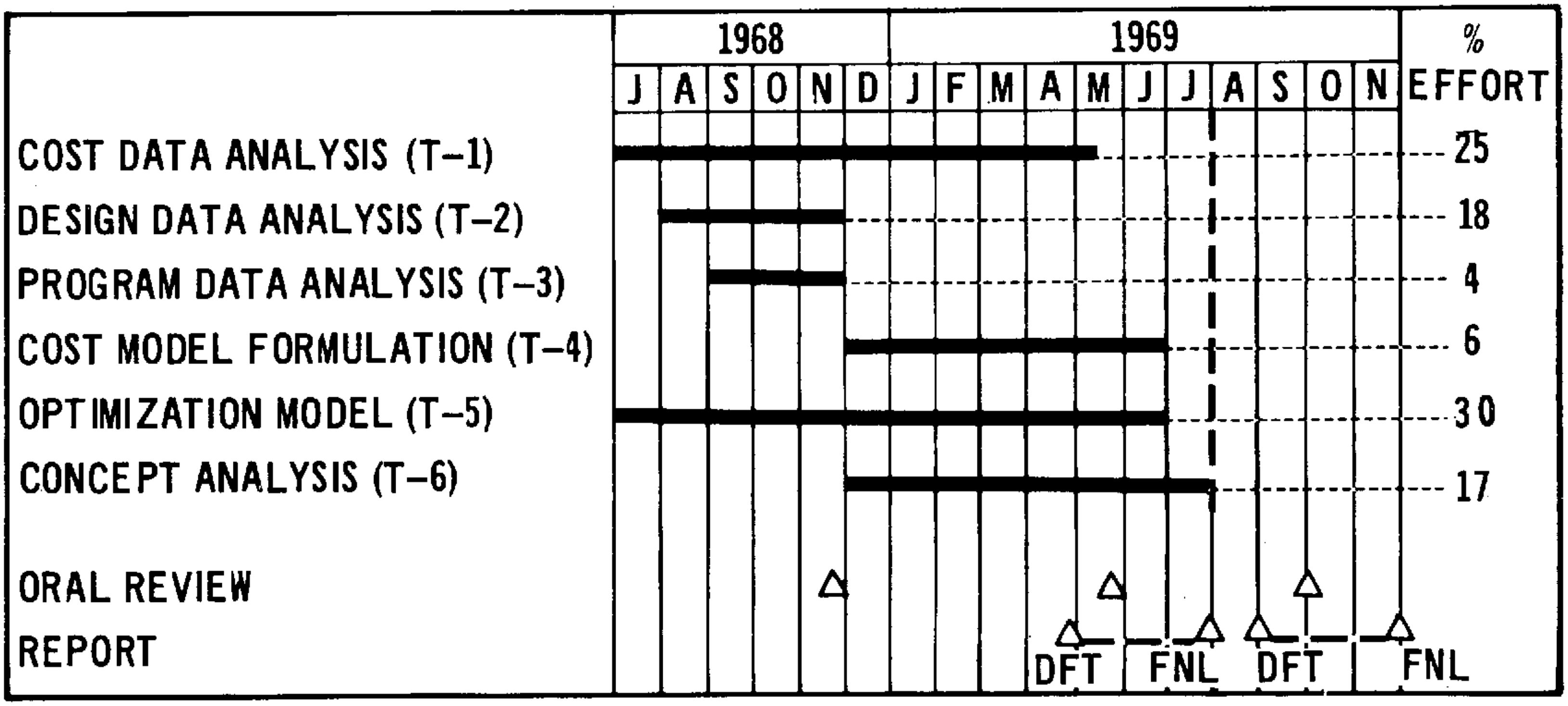
SCHEDULE

The study was initiated in July of 1968 and was divided into six tasks as shown. The primary portion of the effort being reported on at this time is the last task, concept analysis. The other tasks will be treated cursorily since they have been reported previously.

SCHEDULE



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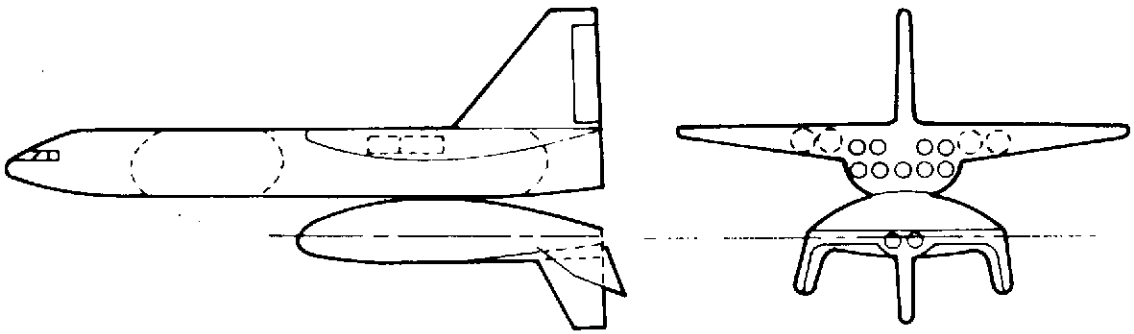
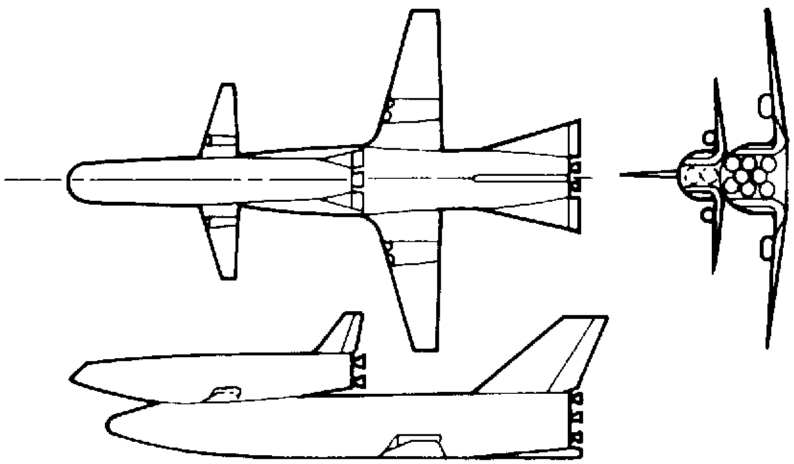
CONCEPTS FOR FUTURE ANALYSIS

Three versions of a fully reusable two stage shuttle will be investigated in additional work. These will be based on current study activities and therefore will reflect the current design and operational philosophies more than the basic study concepts.

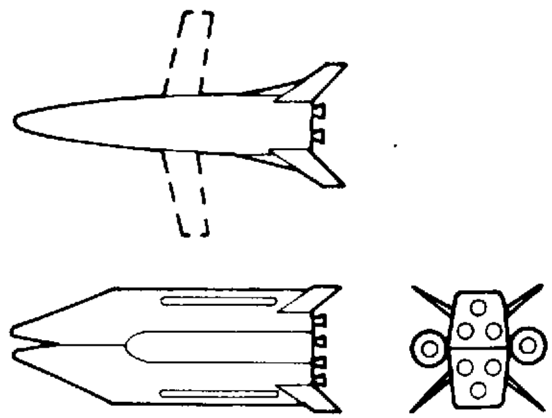
CONCEPTS FOR FUTURE ANALYSIS



CONCEPT L



CONCEPT M



CONCEPT S

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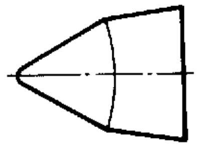
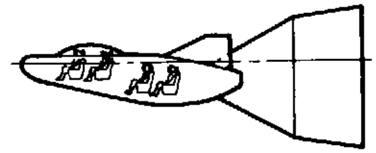
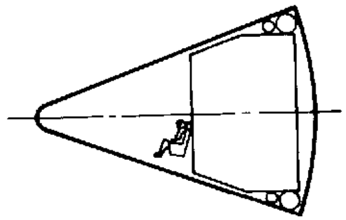
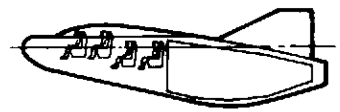
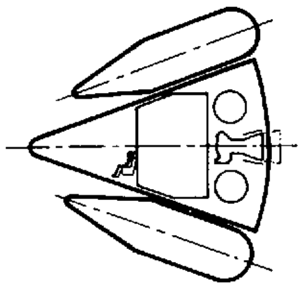
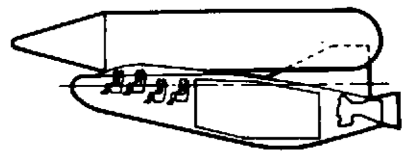
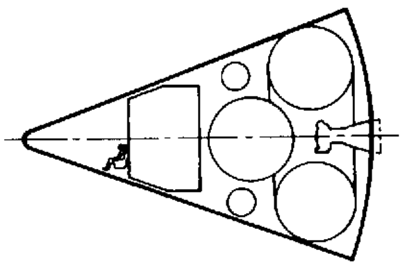
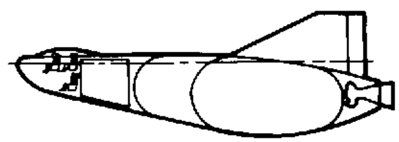
SYSTEM ALTERNATES

(Vehicle Parameters)

Two spacecraft concepts have been investigated across a range of reuse categories. The modular ballistic vehicle has a 30° half cone and all cargo and orbit maneuver propulsion is contained in the mission module. The integral cargo and propulsion concepts IC, ID, IE, use a 20° half cone for the entry vehicle shape to reduce the hammerhead effect that would occur with large vehicles. A ground rule of the study was to allow the spacecraft base diameter to be infinitely variable since the launch vehicle is treated parametrically.

The lifting body spacecraft is an M2-F2 and, as with the ballistic vehicle, is simply scaled to allow for variations in cargo and propellant requirements. The upper stage propellant tanks are separate from the vehicle structure on the ballistic concept; a common bulkhead integral tank is used for the M2-F2.

SYSTEM ALTERNATES

REUSE CATEGORY	AERODYNAMIC CONFIGURATION	
	BALLISTIC	LIFTING BODY
MODULAR EXPENDABLE AND REUSABLE EV	IA IB 	IIA, IIB 
INTEGRAL CARGO AND PROPULSION	IC 	IIC 
INTEGRAL PROPULSION HARDWARE WITH EXPENDABLE TANKS	ID 	IID 
INTEGRAL UPPER STAGE BOOST (EXPENDABLE AND REUSABLE 1ST STAGE)	IE 	IIE, IIF 

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BASIC SPACECRAFT DEVELOPMENT COSTS

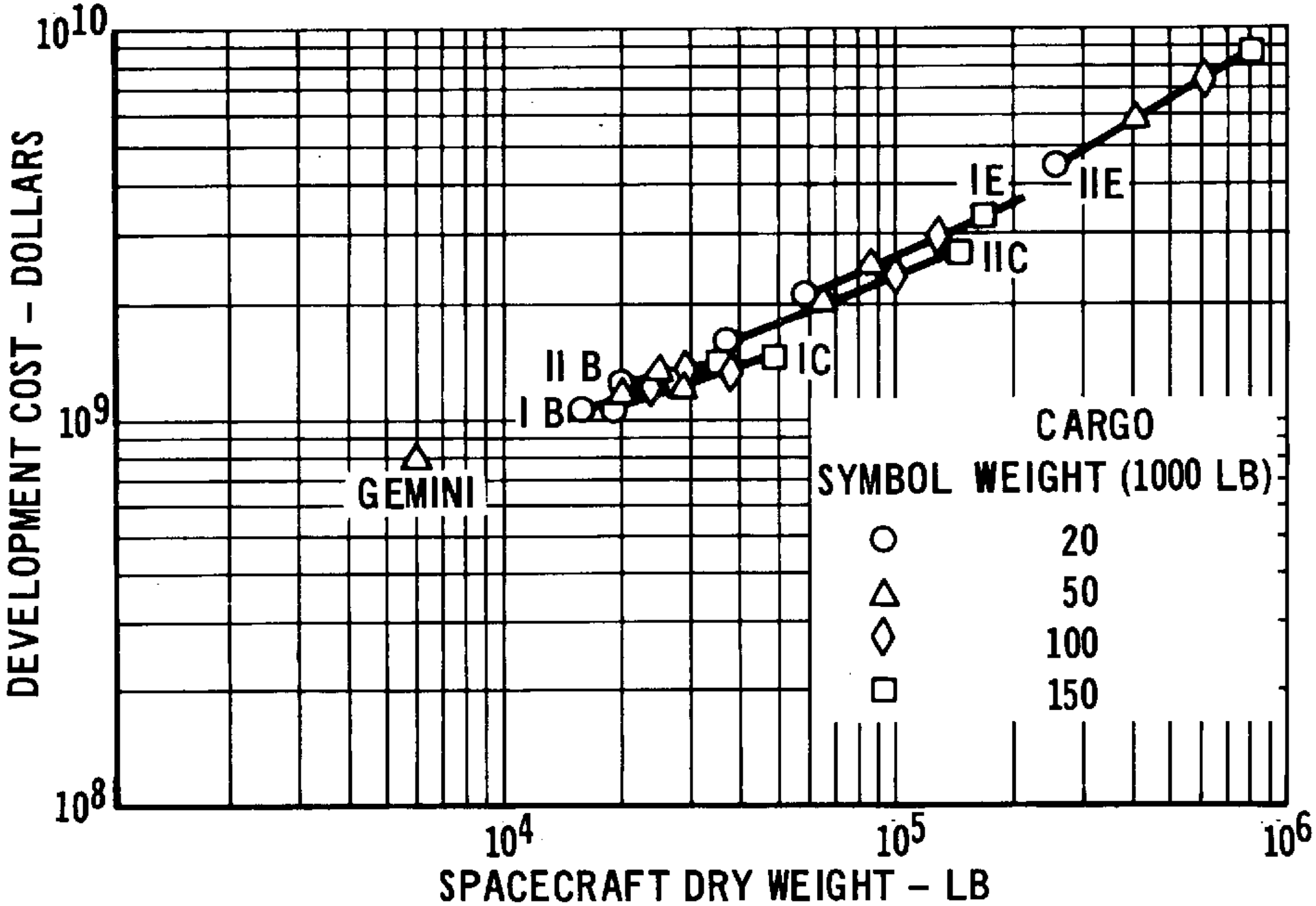
Basic spacecraft development costs are shown for both the ballistic and lifting body vehicles for a range of reuse categories from modular (B) to the reusable upper stage (E). The effect of subsystem costs can be seen in the variation of slope in going from the B to E concepts. For the very large reusable upper stage lifting body spacecraft, the development cost varies almost directly with weight, indicating the dominance of the thermo structure.

BASIC SPACECRAFT DEVELOPMENT COSTS

NOTES:

1) MODULAR CONFIGURATIONS INCLUDE BOTH E.V. AND M.M.

2) BASIC SPACECRAFT COSTS ONLY; EXCLUDES MANAGEMENT AND FEE



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DATA SOURCES

This chart indicates the various sources of data from the McDonnell Douglas Corporation experience and also notes that nineteen subsystem manufacturers provided additional cost and design data in support of the study.

DATA SOURCES

MANNED SPACECRAFT
- MERCURY
- GEMINI
- MOL

UNMANNED SPACECRAFT
- ASSET
- BGRV

LAUNCH VEHICLES
- SATURN S-IVB

AIRCRAFT
- F-4

VENDORS
- NINETEEN COMPANIES – SUBSYSTEM DATA

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VENDOR SUPPORT

McDonnell Douglas gratefully acknowledges the companies which responded to a request for cost and performance data in support of the study.

VENDOR SUPPORT

COMPANY	SUBSYSTEM
AEROJET – GENERAL	PROPULSION
AIRESEARCH	POWER SUPPLY
ALLIS-CHALMERS	POWER SUPPLY
BARNES ENGINEERING	AVIONICS
BENDIX CORPORATION	ENVIRONMENT CONTROL
COLLINS RADIO COMPANY	AVIONICS
HAMILTON STANDARD	ENVIRONMENT CONTROL
HONEYWELL, INC.	AVIONICS
IBM	AVIONICS
LEACH, INC.	AVIONICS
MARQUARDT	PROPULSION
MOTOROLA	AVIONICS
PRATT AND WHITNEY AIRCRAFT	POWER SUPPLY
PRATT AND WHITNEY AIRCRAFT	PROPULSION
ROCKETDYNE	PROPULSION
SPACECRAFT, INC.	AVIONICS
SUNSTRAND AVIATION	POWER SUPPLY
TRW, INC.	PROPULSION
WESTINGHOUSE	AVIONICS

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COST ANALYSIS GROUND RULES AND ASSUMPTIONS

These ground rules and assumptions were established at the start of the study and have been used throughout. The item that has the most effect on the estimated cost of future systems is that the test program will assume 5 flight vehicles and a five flight program.

COST ANALYSIS GROUND RULES AND ASSUMPTIONS

- COST DATA INCLUDES GEMINI S/C, SATURN S-IVB STAGE, MERCURY S/C, ASSET, AIRCRAFT, PREVIOUS STUDIES, AND VENDOR REQUESTED DATA
- DEVELOP A COST ELEMENT STRUCTURE (CES) FOR CATALOGING COST DATA FORMATING THE COST MODEL
- ORGANIZE AND REPORT GEMINI AND S-IVB COST DATA IN ACCORDANCE WITH THE CES.
- GEMINI AND S-IVB COST DATA SHALL INCLUDE 5 FLIGHT VEHICLES AND A 5 FLIGHT TEST PROGRAM
- MID-CALENDER 1969 LABOR RATES SHALL BE USED
- MATERIAL, CFE, AND SUBCONTRACT DOLLARS SHALL BE ADJUSTED TO MID-CALENDER 1969 USING A 5% ANNUALLY COMPOUNDED FACTOR
- A 10% FEE IS TO BE USED AT THE PROGRAM PHASE LEVEL
- A 1963 TECHNOLOGICAL BASE SHALL BE ASSUMED FOR BOTH GEMINI AND S-IVB

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COST ELEMENT STRUCTURE - RDT&E PHASE

I. Research, Development, Test and Evaluation (RDT&E) - commences after the completion of Phased Project Planning (PPP) and includes Phase D design, development and test. Includes all program related costs up to the establishment of an Initial Operational Capability (IOC).

A. Project Management and Administration - project prime contractors cost of managing and integrating the several project elements including all required documentation and software.

II. Spacecraft Project Sements:

A. Entry Vehicle (E/V) - the recoverable portion of the spacecraft.

B. Mission Module (M/M) - expendable cargo and/or propulsion portion of the spacecraft. As a limiting case, consists of the spacecraft to launch vehicle adapter and associated equipment.

C. Aerospace Ground Equipment (AGE) - maintenance and operational ground support equipment used at the several operational and test sites to service, checkout or control the flight vehicle. Includes design, development and build of equipment required to support the RDT&E phase.

D. Launch and Operational Facilities - program peculiar buildings and support installation required to support RDT&E phase.

E. Trainers and Simulators - program peculiar equipment, facilities, and operations required to train the flight crew for the RDT&E phase.

F. System Integration - Engineering mockups, test operations, and hardware expended in support of integrating the several project segments. In general, those costs which cannot be identified by project segment or subsystem.

COST ELEMENT STRUCTURE - RDT&E PHASE (CONTINUED)

III. AVE Subsystem Groups

A. Thermal/Structural System - Includes all basic and secondary members including thrust structure, interstage structure, pressurized and non-pressurized compartments (including hatches, airlocks, windows and ports), fixed and movable control surfaces, fairings and related structure, launch escape tower, internal and external, active and passive insulation, attaching structure and bonding material, landing gear and docking structure, and all separation, ullage, range safety and abort ordnance.

B. Inflatable Aerodynamic Devices - parachute, sailwing or other deployable recovery aid.

C. Power Supply System - Electrical, hydraulic and pneumatic power sources, conversion and distribution equipment and utility provisions (lighting and signal devices).

D. Environmental Control and Life Support Systems - personnel temperature and pressure control and coolant equipment, accommodations (seats, restraints) cargo handling, furnishings, and emergency equipment.

E. Avionics Systems - guidance and navigation (programmer, sensors, inertial platform, gyro, accelerometers, etc.), instrumentation and communication (sensors, signal conditioning, transmitters, receivers, radar, antenna, TV and tracking equipment), computational (computer, interface controller control stands, instrument panels, and crew station flight controls), and range safety and abort (destruct receiver, range safety beacon, power supply and controls).

F. Propulsion - engine and accessories and propellant systems (containers, vent, purge, pressurization, and utilization equipment) for main attitude control and translation, separation, ullage, retro, abort, and landing assist systems.

COST ELEMENT STRUCTURE - RDT&E PHASE (CONTINUED)

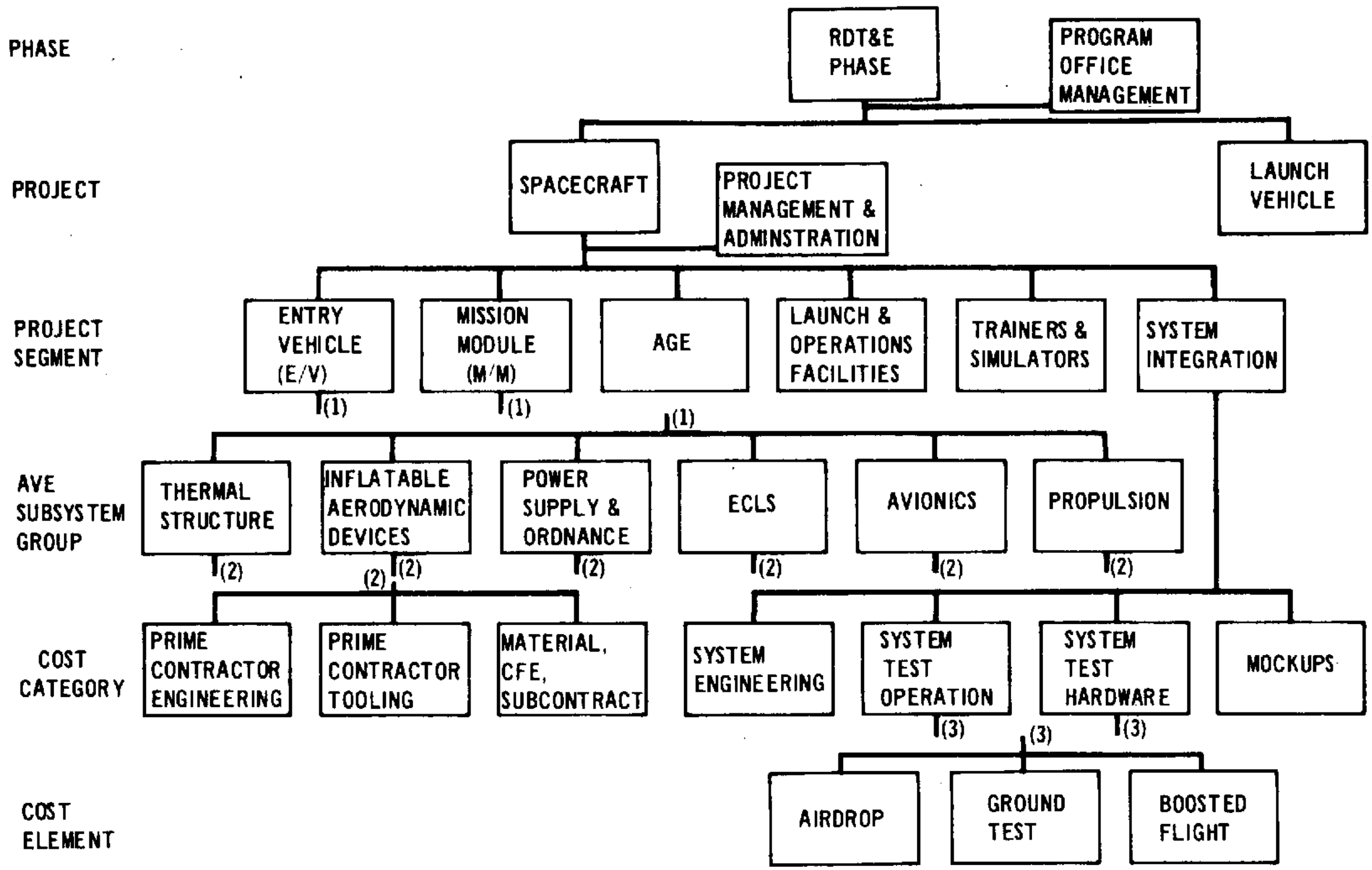
IV. Cost Categories

A. Engineering Design and Development - project engineering, laboratory testing (development, qualification and reliability) shop and vendor liason engineering, and special test articles required to develop and integrate all subsystems.

B. Tooling - design and fabrication of flight and non-flight systems tooling.

C Subcontracts - subcontractor effort to design and develop, test (development, qualification, and reliability) and fabricate test hardware for a total S/C subsystem. Also contains minor purchased parts procured by integrating contractor to support development program.

COST ELEMENT STRUCTURE - RDT&E PHASE



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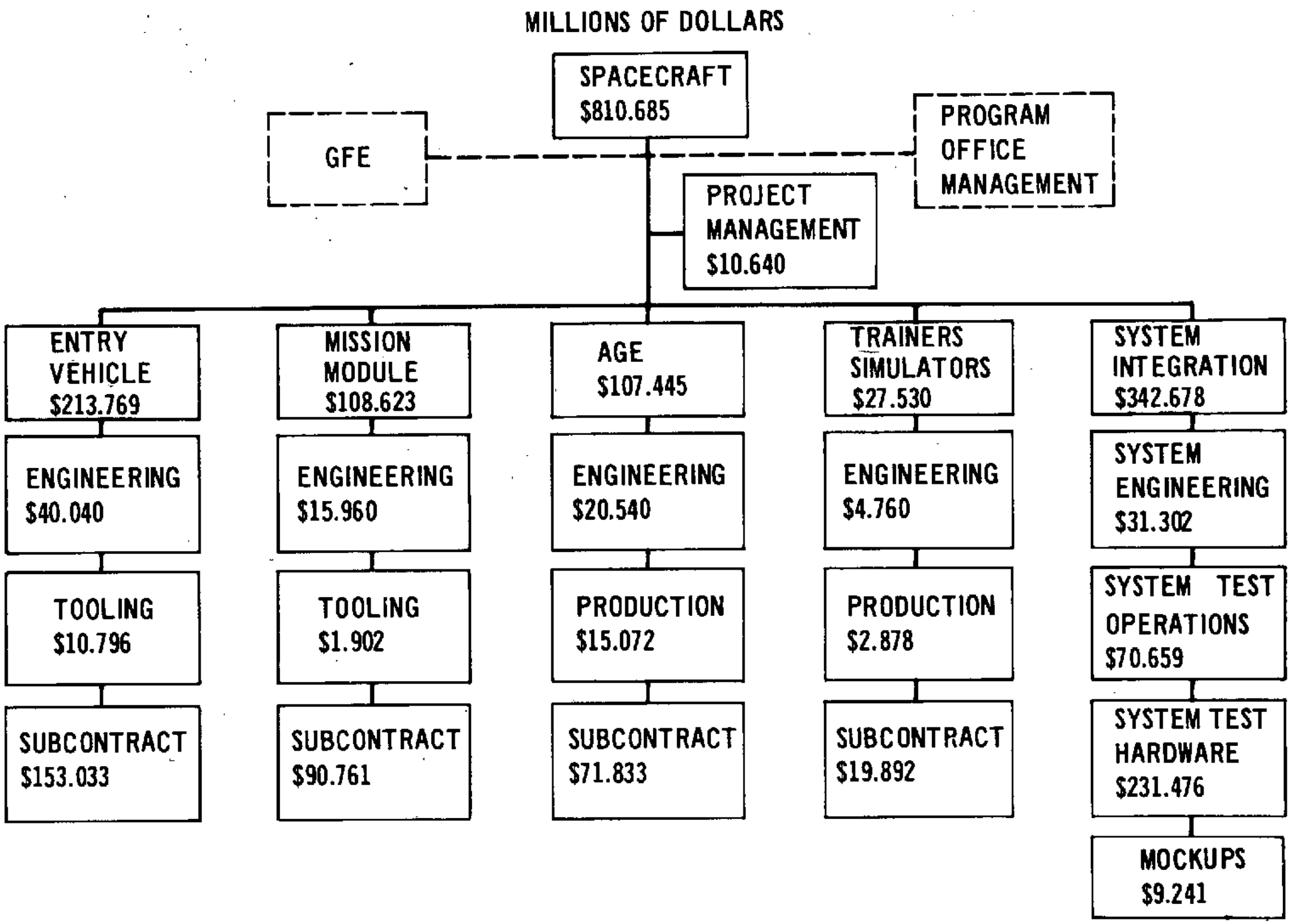
GEMINI COSTS - RDT&E PHASE

The Gemini cost data derived for the OCPDM study is presented in this figure by five major areas. The costs represent the design and development program, AGE, Trainers, and System Integration which include the ground test operations and ground test hardware, flight test operations and flight test hardware for five RDT&E spacecraft as established in the study ground rules. The costs are further segregated by type of labor.

The costs presented here exlcude experiments and the target vehicle docking adapter, and have been organized and adjusted according to the OCPDM study ground rules.

GEMINI COSTS - RDT&E PHASE



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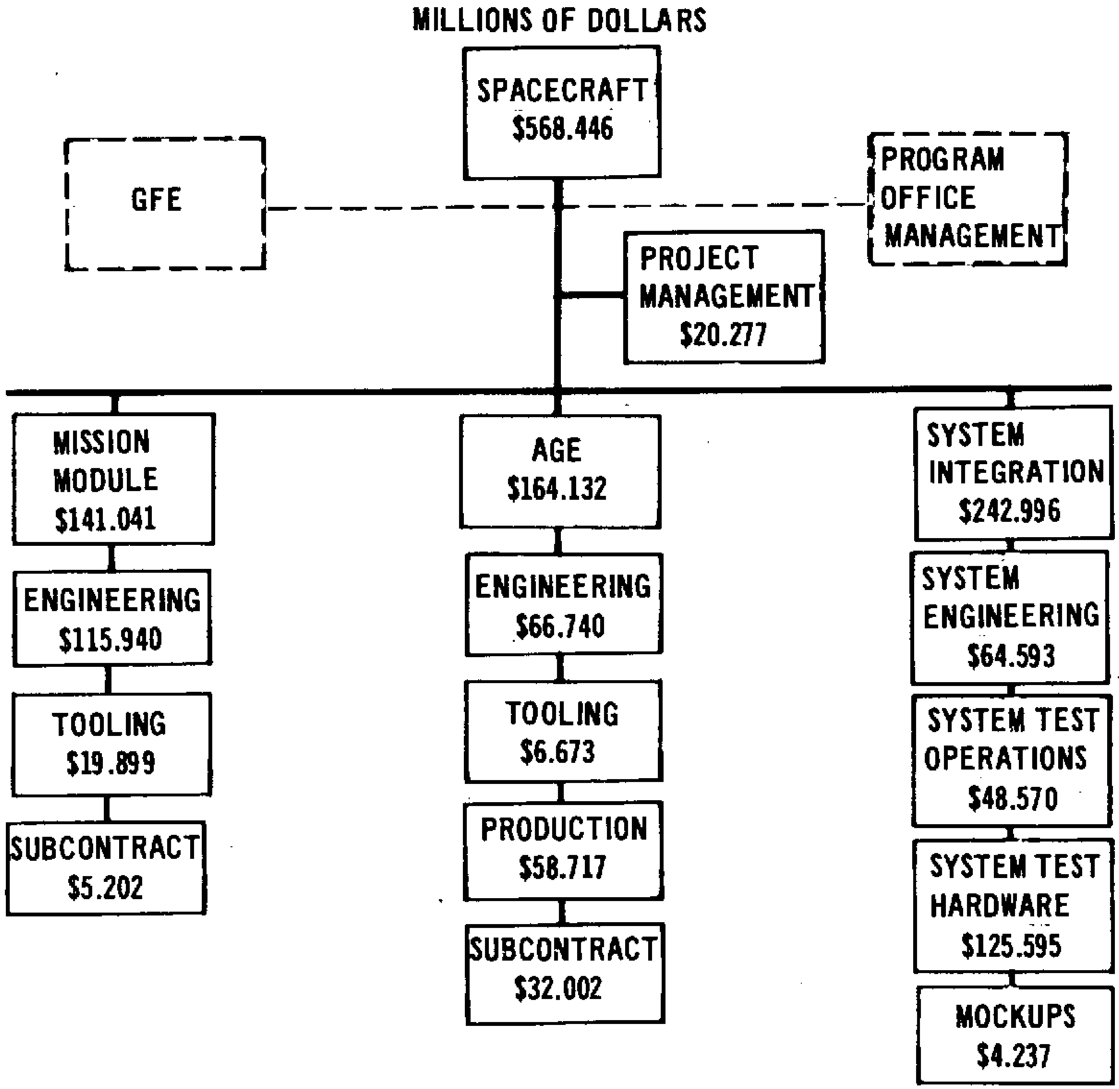
SATURN S-IVB COSTS - RDT&E PHASE

The SIVB cost data derived for the OCPDM study is presented in this figure by the three major areas. The costs represent the design development program, AGE, and System Integration which include the ground test operations and ground test hardware, flight test operations and flight test hardware for 5 vehicles. The major areas of cost are further segregated by type of labor. The cost data presented here have been organized and adjusted according to the OCPDM study ground rules.

SATURN S-IVB COSTS - RDT&E PHASE



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CER DEVELOPMENT

The steps required in developing cost estimating relationships are analogous to those which must be followed in deriving any semi-empirical relationship. The major problem is organization and normalization of the raw data.

CER DEVELOPMENT

- ORGANIZE AND ANALYZE COST HISTORY
- DEVELOP PERTINENT DESIGN DATA
- UTILIZE DESIGN DATA THAT WILL BE AVAILABLE TO THE USER
- PLOT COST VS DESIGN DATA
- RELATE COST TO DESIGN DATA
- EXAMINE COST DATA IN FURTHER DETAIL FOR PECULIARITIES WHEN NECESSARY
- ANALYZE CER FOR EXTRAPOLATION AND FUNDAMENTAL ESTIMATING ABILITY

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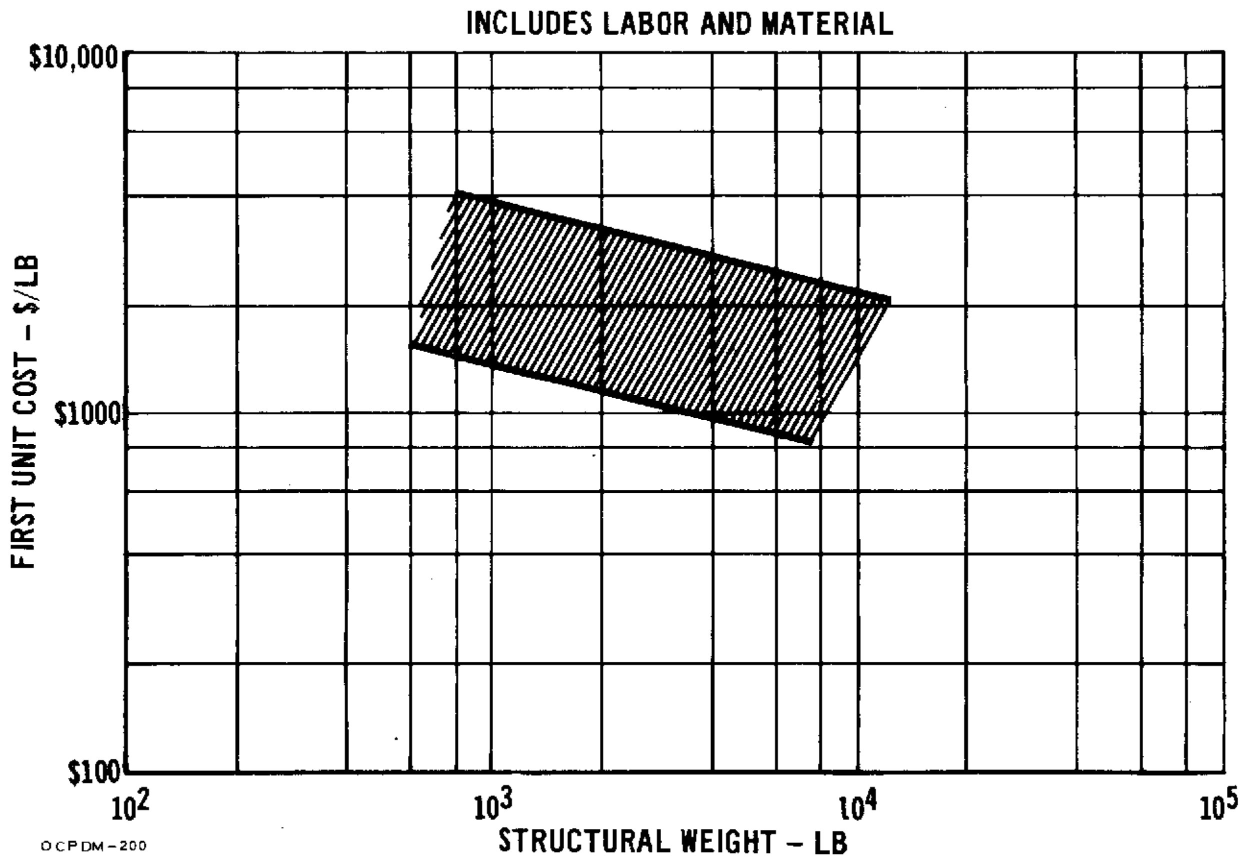
ENTRY VEHICLE STRUCTURE FIRST UNIT COST

This shows first unit procurement costs for the entry vehicle structures and materials, showing the spread of the basic data after the adjustments for accounting type differences, economic base, etc., but prior to any analysis of design characteristics. These data indicate about a factor of three spread in the cost and of course do not lend themselves to the development of a cost estimating relationship without further normalization of the data. The data have already been grouped according to the primary application (i.e. entry vehicle, aero surfaces, simple adapter, etc.) so that type of material and type of construction are the next obvious parameters to examine.

ENTRY VEHICLE STRUCTURE



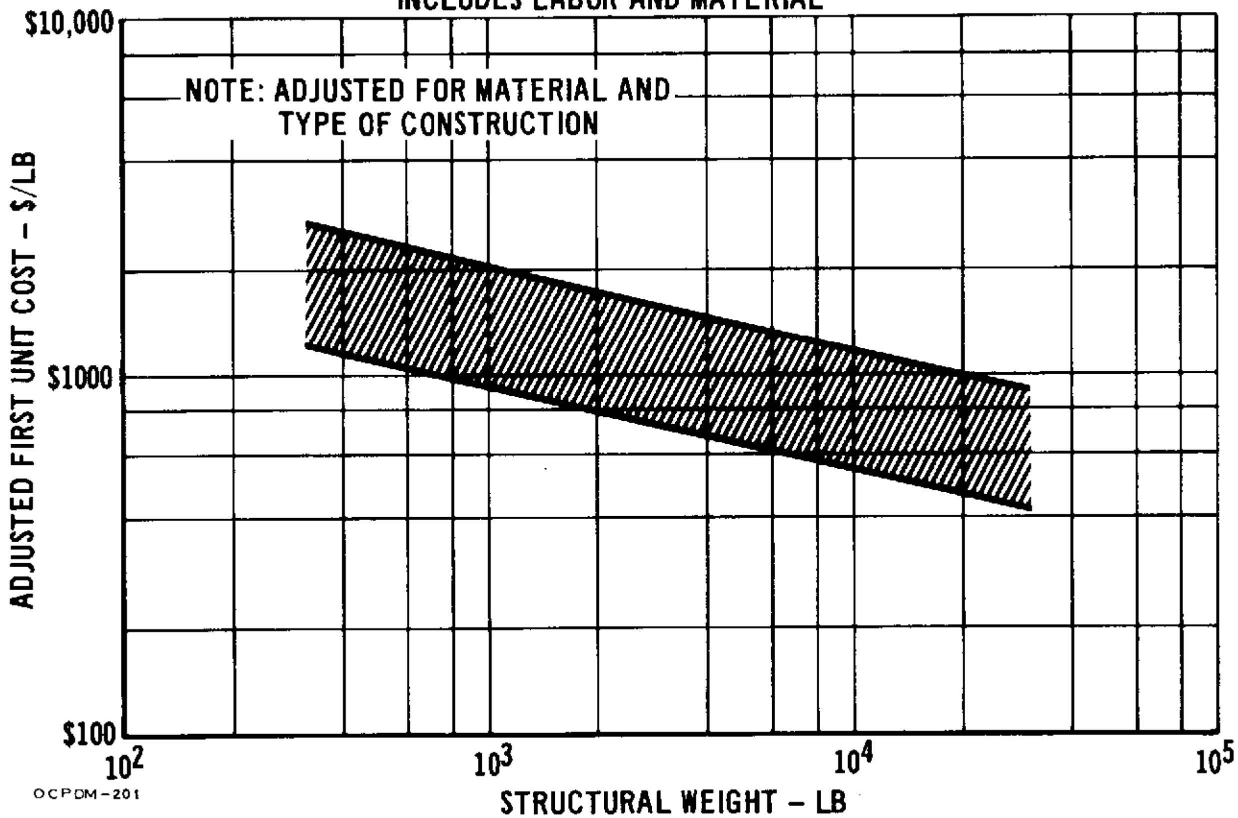
ENTRY VEHICLE STRUCTURE FIRST UNIT COST

(Adjusted for Material and Type Construction)

Based on many years of experience in working with various materials and construction techniques, semi-empirical relationships have been derived which were applied to these data. These are referenced to aluminum skin stringer construction and the data spread has been narrowed from a factor of 3 to a factor of 2.

ENTRY VEHICLE STRUCTURE
ADJUSTED FIRST UNIT PROCUREMENT COST

INCLUDES LABOR AND MATERIAL



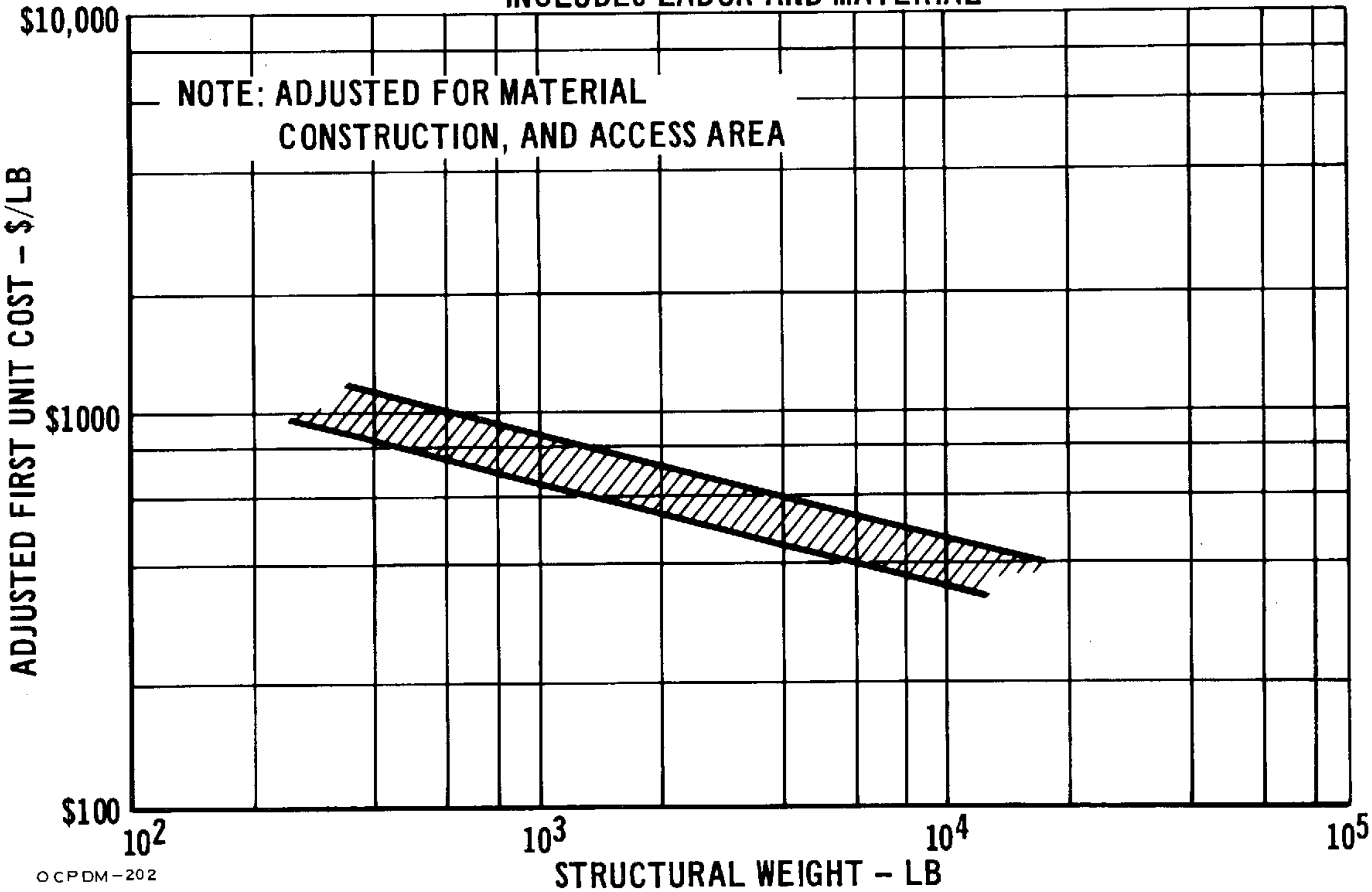
ENTRY VEHICLE STRUCTURE FIRST UNIT COST

(Adjusted for Material and Type Construction and Access Area)

At this point it was necessary to look at each vehicle in more detail and it was determined that one of the most outstanding differences was the percentage of the wetted area which was used for access doors, hatches, windows, etc. Therefore, an area factor was derived based on the ratio of the hatches, doors, and windows to the total wetted area. Applying this factor narrowed the spread of data to about $\pm 10\%$ around the equation which was derived.

ENTRY VEHICLE STRUCTURE

ADJUSTED FIRST UNIT PROCUREMENT COST
INCLUDES LABOR AND MATERIAL



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TYPICAL COST ESTIMATING RELATIONSHIPS

(Structure - First Unit)

The equation that results from the previous data is shown. Weight is the primary estimating parameter but the costs of various sections are estimated separately, and adjustments are applied for the type material and construction, and for the amount of the surface used for cutouts.

TYPICAL COST ESTIMATING RELATIONSHIPS (STRUCTURE - FIRST UNIT)

CREW SECTION COST $= 3950(W_S)^{-0.234}(W_S)(K_{MC})\left[4\frac{A_{HD}}{A_T}+1\right]$

CARGO/PROPULSION SECTION $= 2250(W_S)^{-0.234}(W_S)(K_{MC})\left[4\frac{A_{HD}}{A_T}+1\right]$

NOTE:

W_S = STRUCTURE WEIGHT

K_{MC} = MATERIAL COMPLEXITY FACTOR

A_{HD} = AREA OF HATCHES, DOORS, AND WINDOWS

A_T = TOTAL WETTED AREA

OCPDM-284

LAUNCH VEHICLE DEVELOPMENT COST TRENDS

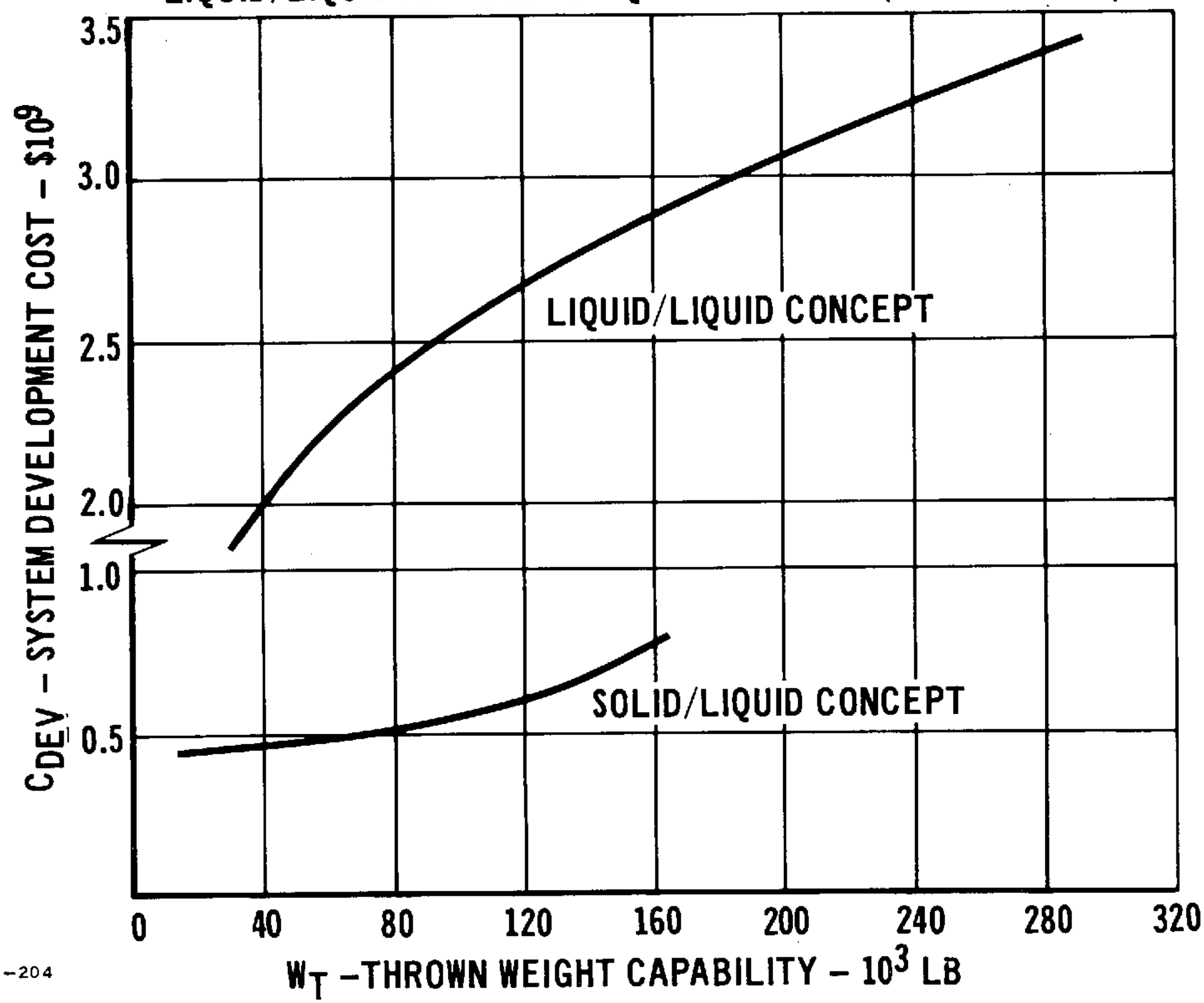
The development of detailed launch vehicle cost analysis sub-routines was not included in this study due to funding limitations and a desire to concentrate on the spacecraft segment of the system. Consequently, the launch vehicle analysis consisted of formulating gross cost-performance relationships for one or more concepts within each launch vehicle class.

The solid boosted/liquid concept consists of an expendable two staged tandem vehicle employing 156-inch diameter solid rocket motors (SRM) first stage and a cryogenic (LO_2/LH_2) upper stage for the small payload sizes. As payload requirements increase, additional SRM's (to a maximum of 4) are added to and zero staged from the core first stage.

The second two stage all expendable concept is a LO_2/RP first - LO_2/LH_2 second stage vehicle as represented by the current Saturn family of launch vehicles. In fact, three Saturn point designs (up-rated Saturn I, S-IC/S-IVB, and S-IC/S-II) were used to estimate the cost performance characteristics of this concept, which results in the indicated range of thrown weight capabilities.

LAUNCH VEHICLE DEVELOPMENT COST TRENDS

LIQUID/LIQUID AND SOLID/LIQUID CONCEPTS (1969 DOLLARS)



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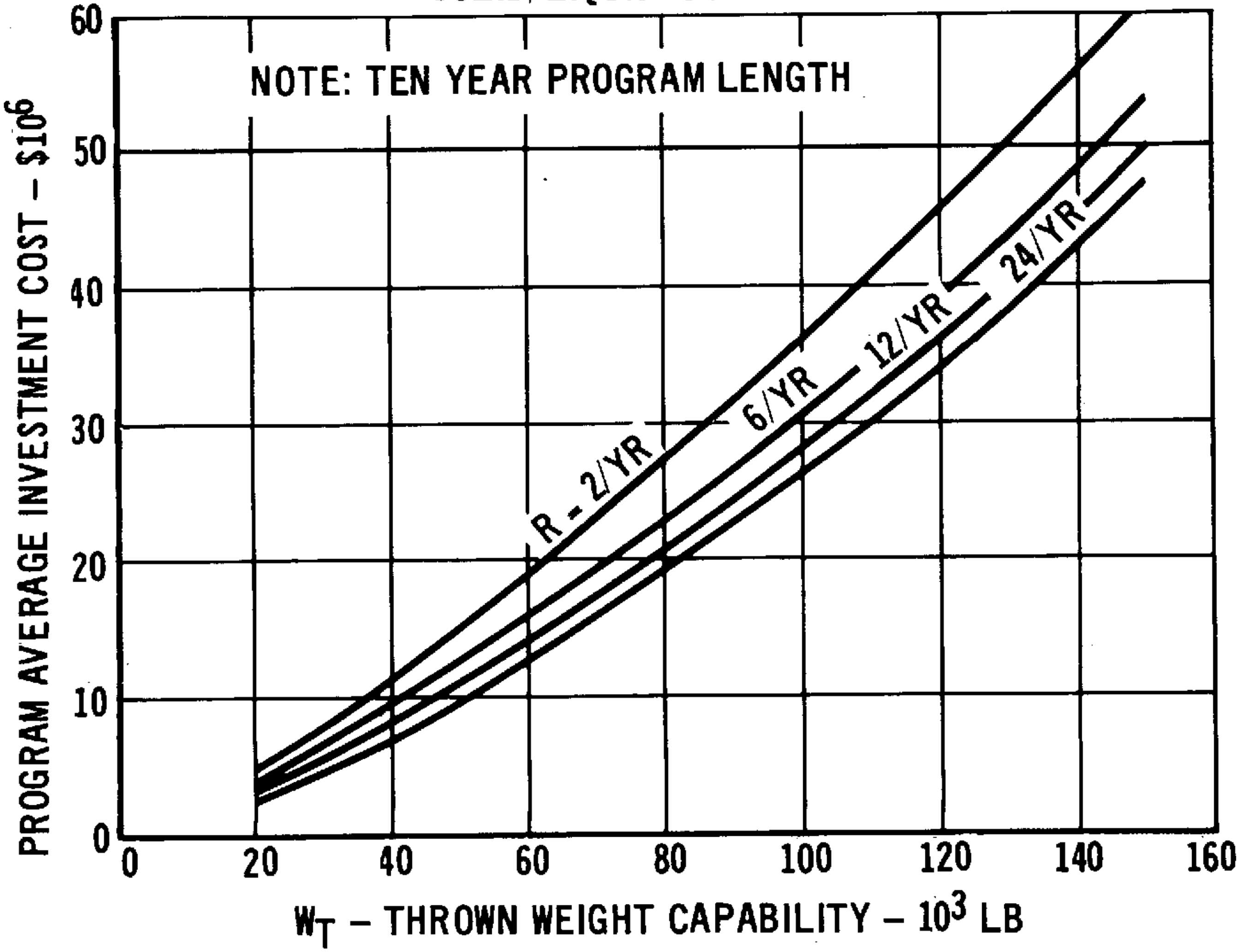
LAUNCH VEHICLE INVESTMENT COST TRENDS

(Solid/Liquid L.V. Concept)

The investment cost category is the same as that employed for the spacecraft portion of the system and includes the manufacturing cost and sustaining engineering associated with the production of all flight hardware used in the operational phase of the program.

LAUNCH VEHICLE INVESTMENT COST TRENDS

SOLID/LIQUID CONCEPTS



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DESIGN EFFORT

The design task is outlined, indicating the parametric approach which has been used throughout the study.

DESIGN EFFORT

- DEFINE ENTRY VEHICLE CONCEPTS
- DETERMINE SUBSYSTEM REQUIREMENTS
- DEFINE ALTERNATES FOR EACH SUBSYSTEM
- CHOOSE BASELINE SUBSYSTEMS
- VERIFY SIZING PROGRAM AND MODIFY WHERE NECESSARY
- PROVIDE INPUTS FOR SIZING PROGRAM

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BASELINE SUBSYSTEMS

A set of baseline subsystems were established to be used for a reference during the subsystem trade-offs in the cost analysis. These were based on engineering judgement and limited cost data, but cost was considered in making the selection. In some cases, these were shown to be least cost approaches but in others they were not.

BASELINE SUBSYSTEMS

- STRUCTURE – ALUMINUM – SHEET STRINGER WITH FRAMES
- THERMAL PROTECTION – RADIATIVE PANELS FOR TEMP LESS THAN 3100°F
  ABLATIVE PANELS FOR TEMP ABOVE 3100°F
- ORBITAL MANEUVER – MODULAR – ASCENT/DOCKING/PHASING/ATTITUDE CONTROL NTO/MMH
  DEORBIT SOLID
  INTEGRAL – ALL FUNCTIONS NTO/MMH
- UPPER STAGE BOOST – H_2/O_2 WITH BELL NOZZLE ENGINE
- ELECTRICAL POWER – EXPENDABLE – BATTERIES
  REUSABLE – FUEL CELLS/BATTERIES
- HYDRAULIC POWER – MONOPROPELLANT TURBINE
- ECS – 5PSI O_2 ATMOSPHERE STORED GASEOUSLY, LiOH, WATER BOILER (W/RADIATOR ON MODULAR VEHICLES)
- GUIDANCE & CONTROL – WATER LANDING – SINGLE IMU COMPUTER & FCS
  LAND LANDING – DUAL IMU'S COMPUTERS, AND FCS
  INTEGRAL UPPER STAGE – TRIPLE IMU, DUAL COMPUTERS, AND TRIPLY REDUNDANT FCS FOR LIFTING BODY
- TELECOMMUNICATIONS – UNIFIED S-BAND WITH SEPARATE RADAR

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BASELINE SUBSYSTEMS (Continued)

• LAUNCH ESCAPE	LOW ALTITUDE	HIGH ALTITUDE
BALLISTIC – MODULAR	TOWER	MAIN MANEUVER
INTEGRAL	TOWER	INTERNAL SOLIDS
LIFTING – MODULAR	STRAP ON	MAIN MANEUVER
INTEGRAL	STRAP ON	INTERNAL SOLID

• ENTRY ATTITUDE CONTROL — PRESSURE FED NTO/MMH – DUAL REDUNDANT SYSTEMS

• LANDING ASSIST
- BALLISTIC – SOLIDS FOR VERTICAL VELOCITY ATTENUATION
- LIFTING – SOLIDS FOR GLIDE RANGE EXTENSION

• RECOVERY
- BALLISTIC – SAILWINGS FOR MODULAR LAND LANDING
  – RING SAILS FOR ALL OTHER
- LIFTING – RING SAILS FOR ABORT

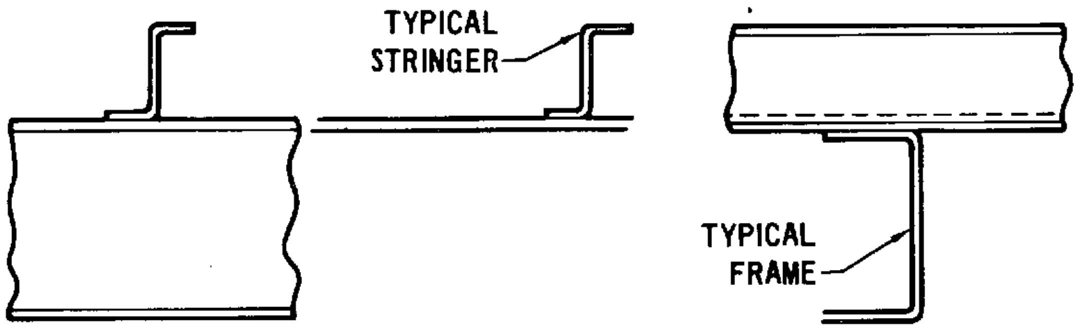
OCPDM-193

PRIMARY STRUCTURE CONCEPTS

Three structural concepts and four types of materials can be examined for the primary body structure. Aluminum sheet stringer with frames is used as the baseline for all configuration concepts.

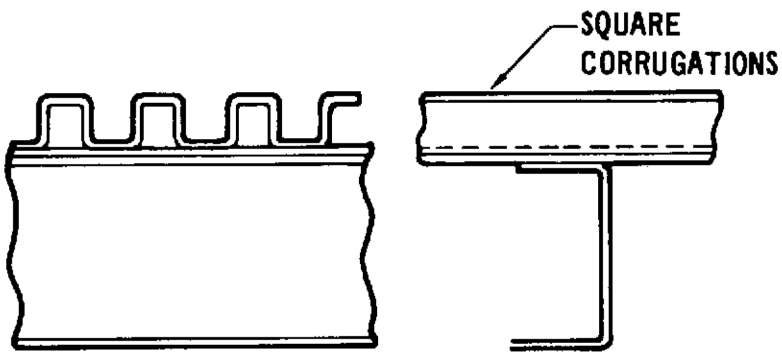
PRIMARY STRUCTURE ALTERNATES

SHEET-STRINGER WITH FRAMES

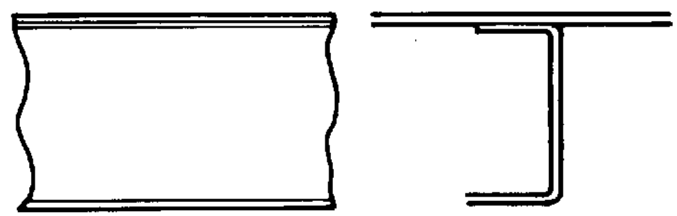


MATERIALS
ALUMINUM ALLOY
TITANIUM ALLOY
MAGNESIUM ALLOY
STAINLESS STEEL

SINGLE SKIN, SQUARE CORRUGATIONS WITH FRAMES



SINGLE SKIN WITH FRAMES

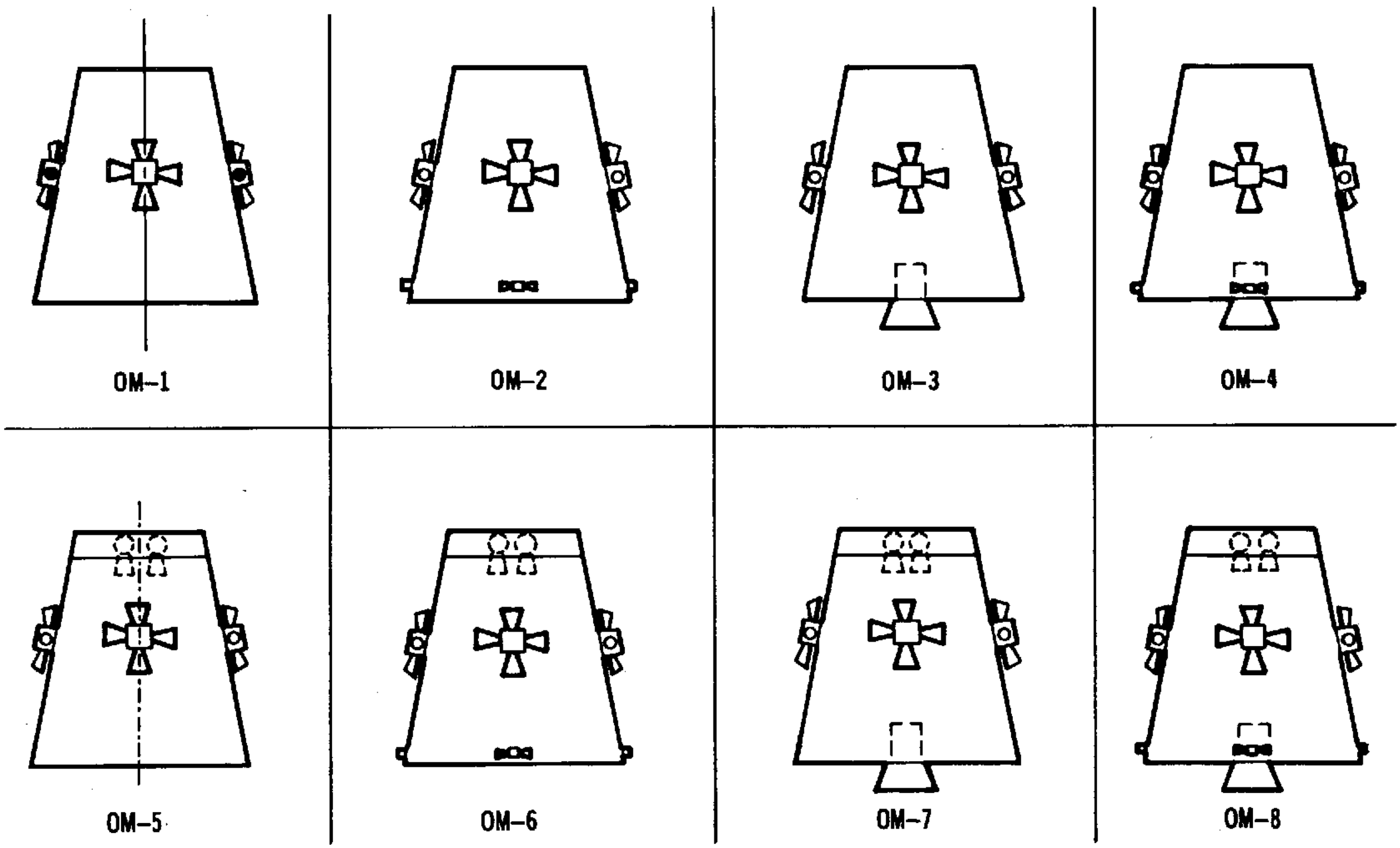


OCPDM-278

ORBITAL MANEUVER SYSTEM ALTERNATES

Orbit maneuver system alternates are shown. This system accomplishes all maneuvers required for transfer and injection from a 100 n. mi.orbit to a 300 n. mi orbit, rendezvous, dock, attitude control, orbit phasing if necessary, and deorbit. The first approach shown accomplishes all of these with four quads of engines, located symmetrically around the module. The second approach separates the attitude control to take advantage of a better moment arm and smaller ACS engines. The third approach uses a large single high energy propellant engine to accomplish the larger maneuvers of orbit transfer, phasing, and deorbit. This might be especially attractive for configurations which require delivery of very large amounts of cargo. The fourth approach is the same as the third with a separate ACS. Concepts, five, six, seven, and eight are the same as one, two, three, and four respectively except that the deorbit maneuver is accomplished with solid rockets. Engine size, propellant requirements, etc. are determined in the sizing model for the particular vehicle under investigation, and provided as part of the input data to the cost model.

ORBITAL MANEUVER SYSTEM ALTERNATES

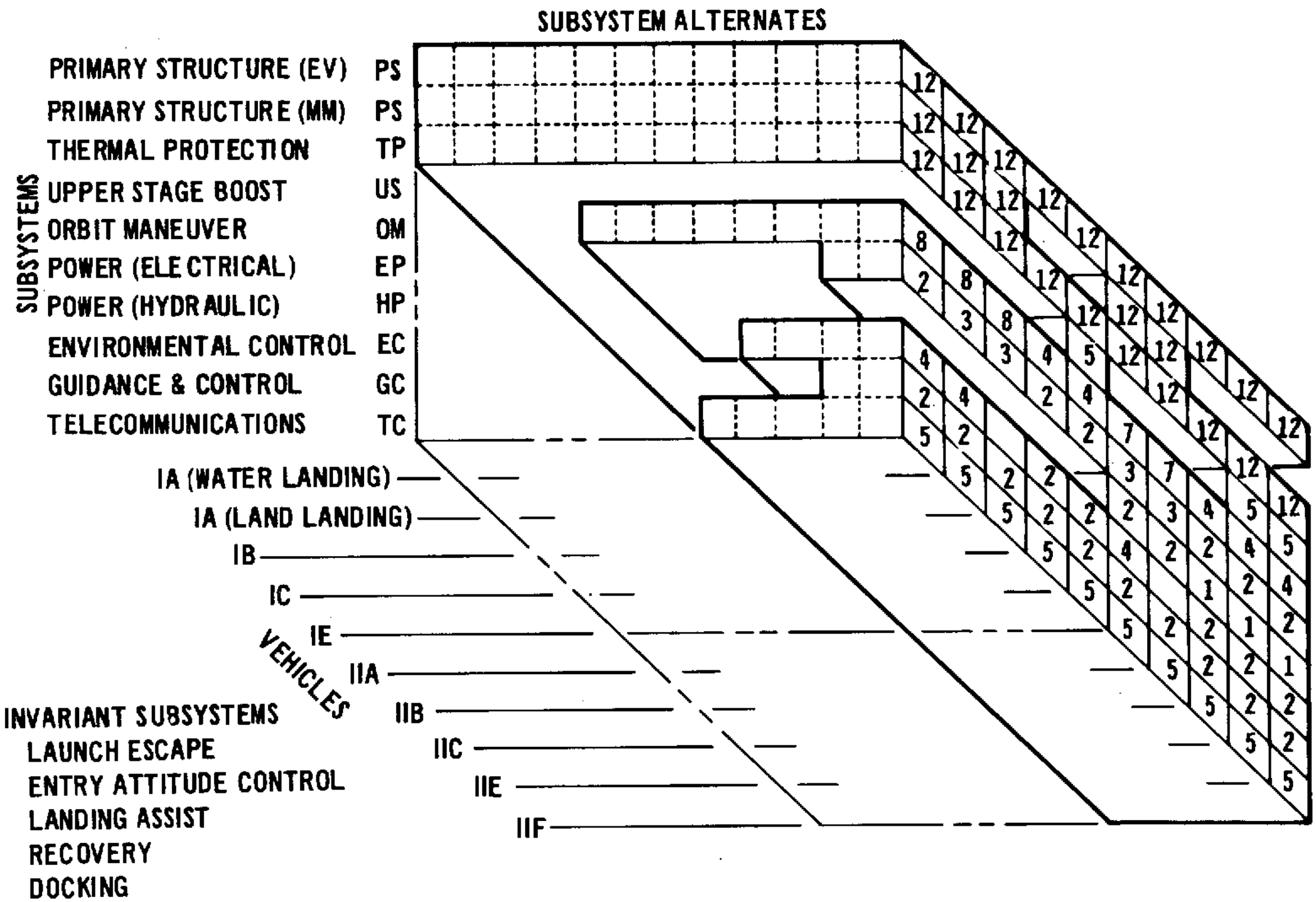


OCPDM-233

SUBSYSTEM MATRIX

The design task defined several alternate approaches for most subsystems, each capable of meeting the performance requirements which were established. This summarizes the number of alternates for each subsystem for each spacecraft concept which can be investigated. For instance, the IA (water landing) concept has 12 possible approaches of material and construction for primary structure; 8 orbit maneuver, etc. The product of all the combinations for a IA spacecraft exceed a million and obviously were not all investigated during the study.

SUBSYSTEM MATRIX



OCPDM-191

OPERATIONAL SYSTEM ALTERNATES

One of the study objectives was to investigate various operational modes. Alternates were defined for seven of the operation functions and the associated cost and schedule effects were defined. The details of the alternates are described in Volume II Book 2.

OPERATIONAL ALTERNATES

PARAMETER	ALTERNATES	ALTERNATE NUMBER
LAUNCH OPERATIONS	BUILDUP & CHECKOUT AT LAUNCH SITE INTEGRATED CHECKOUT AT PAD	1 2
AGE APPROACH	SEMI-AUTOMATIC ON-BOARD CHECKOUT	1 2
REFURBISHMENT PHILOSOPHY	SCHEDULED MAINTENANCE & TESTING (W/HOT FIRINGS) SCHEDULED MAINTENANCE & TESTING (WITHOUT HOT FIRINGS) LIMITED SCHEDULED MAINTENANCE	1 2 3
REFURBISHMENT SITE	FACTORY NEW SITE	1 2
RECOVERY MODE	LAND WATER	1 2
RECOVERY SITE	TWO NEW SITES TWO EXISTING SITES THREE EXISTING SITES FOUR EXISTING SITES	1 2 3 4
TRANSPORTATION MODE	WATER LAND AIR	1 2 3

OCPDM-219

MAJOR COMPONENTS OF MODEL

The model really consists of a series of sub models, the two largest of which are SIZE and COST. SIZE is a parametric design model that contains non dimensionalized spacecraft geometry characteristics, descriptions of all the subsystems, and the ability to investigate various aerodynamic and thermodynamic conditions with respect to the induced loads and temperatures. The vehicle is scaled to accommodate variations in volume requirements.

COST simply takes the vehicle definition provided by SIZE, uses these in the cost estimating equations, and sums the results.

MAJOR COMPONENTS OF MODEL

- EXECUTIVE – CONTROLS CALL-UP OF OTHER MODULES OF THIS MODEL
- SIZE – GENERATES DESCRIPTION & WEIGHT STATEMENT FOR SELECTED VEHICLE CONFIGURATION AND OPTIMIZED CARGO SIZE.
- COST – GENERATES DETAILED PROGRAMMATIC COST STATEMENT FOR OPTIMIZED VEHICLE
- INVENTORY – COMPUTES THE NUMBER OF VEHICLES REQUIRED TO ACCOMPLISH SPECIFIED MISSION
- CARGO OPTIMIZATION – DETERMINES PER-FLIGHT CARGO SIZE PRODUCING LEAST TOTAL PROGRAMMATIC COST UTILIZING SIZE, COST & INVENTORY
- LAUNCH VEHICLE COST MODEL – PROVIDES LAUNCH VEHICLE DEVELOPMENT, INVESTMENT AND OPERATIONAL COSTS AS A FUNCTION OF THROWN WEIGHT CAPABILITY
- RELIABILITY REALLOCATION – REDUCE TOTAL COSTS WITHOUT LOSS OF OVERALL RELIABILITY
- RECERTIFICATION FLOW TIME – DETERMINES CALENDER FLOW TIME AS FUNCTION OF VEHICLE SIZE AND TYPE

OCPDM–209

SOME USER INPUTS

The model was prepared in such a way as to make it easy for a potential user in terms of the number and kind of inputs required to run the model. They are primarily mission and program oriented and therefore, do not require the user to have extensive technical background in any given technology. A wide variety of alternate approaches have been built in the model for each subsystem and can be investigated with only an input flag.

SOME USER INPUTS

- TYPE OF VEHICLE
- DEGREE OF REUSABILITY
- CREW SIZE
- CARGO PER FLIGHT OR TOTAL LAUNCH RATE
- TOTAL SUBSYSTEM RELIABILITY
- PROGRAM LENGTH
- OPERATIONS VARIATIONS DESIRED
- OPTIONAL OUTPUTS
- FIXED SUBSYSTEM COMPOSITION
- PROBABILITY OF MISSION SUCCESS
- COST BASE YEAR
- ETR/WTR LAUNCH
- CARGO DENSITY
- LV THROW WEIGHT CAPABILITY
- ORBIT INCLINATION
- INFLATION RATE
- UPPER AND LOWER LIMITS FOR GOLDEN RULE
- LAUNCH VEHICLE TYPE
- LABOR RATES:
  - ENGINEERING
  - PRODUCTION
  - TOOLING
  - REMOTE SITE
- ORBIT STAY TIME
- RETURN TIME
- IMPROVEMENT RATE ON RECOVERY TO LAUNCH TIME

OCPDM-210

COST OUTPUT OPTIONS

The user may request data from the computer program to be summarized or formulated in several ways, including summaries at the module or subsystem level, and organized by program phase or by labor category.

COST OUTPUT - OPTIONS

SPACECRAFT (S/C)
ENTRY VEHICLE (E/V)
THERMAL/STRUCTURE
INFLAT. AERO DEVICES
POWER SUPPLY & OR

OCPDM COST SUMMARY 2

CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM

RDT&E PHASE
SPACECRAFT
ENTRY VEHICLE
MISSION MODULE
SUBTOTAL
AGE
LAUNCH

OCPDM COST SUMMARY 3

ENGINEERING LABOR	TOOLING LABOR	PRODUCTION LABOR	MATL. CFE SUBCONTRACT	REMOTE SITE & CUSTOMER	TOTAL PROGRAM

RDT&E PHASE
SPACECRAFT (EXCLUDES FEE)
SPACECRAFT PROJECT MGMT
TOTAL BASIC SPACECRAFT
E/V & M/M DESIGN & DEVEL.
ENTRY VEHICLE DESIGN & DEVEL.

THERMAL/STRUCTURE
CREW SECTION
DESIGN
TEST
TOOLING
CARGO/PROPULSION SECTION
DESIGN

OCPDM COST SUMMARY 4

ENGINEERING LABOR	TOOLING LABOR	PRODUCTION LABOR	MATL. CFE SUBCONTRACT	REMOTE SITE & CUSTOMER	TOTAL PROGRAM
XXXXX.XXX	XXXXX.XXX	XXXXX.XXX	XXXXX.XXX	XXXXX.XXX	XXXXX.XXX

OCPDM-211

COMPUTER MODEL CHARACTERISTICS

The cost and optimization model was developed for the IBM 360/75 and is written in Fortran IV language. The program is so large that it was necessary to overlay but running time is only about 0.75 minutes per case.

COMPUTER MODEL CHARACTERISTICS

- OPERATING ON IBM 360/75
- COMPUTER LANGUAGE
  - FORTRAN IV
  - RELEASE 16
- SIZE – 560 – 600 K BYTES
  (REQUIRES OVERLAY)
- RUN TIME
  ~ 0.75 MIN/CASE + ~ 2 MIN IN/OUT

OCPDM-208

BASELINE CONDITIONS FOR COST DATA DEVELOPMENT

The baseline conditions are shown and apply to all cost data unless specified otherwise on a particular chart. Variations of these conditions were investigated and sensitivities are shown on other charts for crew sizes ranging from 2 to 12, annual cargo sizes up to 2 million pounds, and a cargo density of 5 lbs/ft^3.

BASELINE CONDITIONS FOR COST DATA DEVELOPMENT

CREW SIZE	9 MEN
ANNUAL CARGO	250,000 LB
PROGRAM LENGTH	10 YEARS
CARGO DENSITY	10 LB/FT^3
ORBIT	300 NM, 50^0
RETURN TIME	24 HR
LAUNCH VEHICLE:	
MODULAR SPACECRAFT	2 STAGE SOLID/LIQUID EXPENDABLE
INTEGRAL UPPER STAGE	260 IN. SOLID EXPENDABLE
PROBABILITY OF MISSION SUCCESS	0.95 WITH 90% CONFIDENCE
PROBABILITY OF SUCCESSFUL CREW RECOVERY	0.995

LABOR RATES ($/HR)
ENGINEERING 20.00 TOOLING 13.40 PRODUCTION 11.80 REMOTE SITE 16.00

OCPDM-270

EFFECT OF CARGO WEIGHT PER LAUNCH ON TOTAL PROGRAM COST
(Ballistic Vehicles)

The costs shown here are total program costs and, in addition to the basic cost, include the contractors fee, the prime contractor cost of managing project segments, and the NASA cost of managing the total program.

These total program costs are based on the baseline conditions and therefore reflect a varying number of vehicles and launches. Thus as the cargo weight per launch is increased and fewer flights are required to support a fixed program, the benefits from learning decreases.

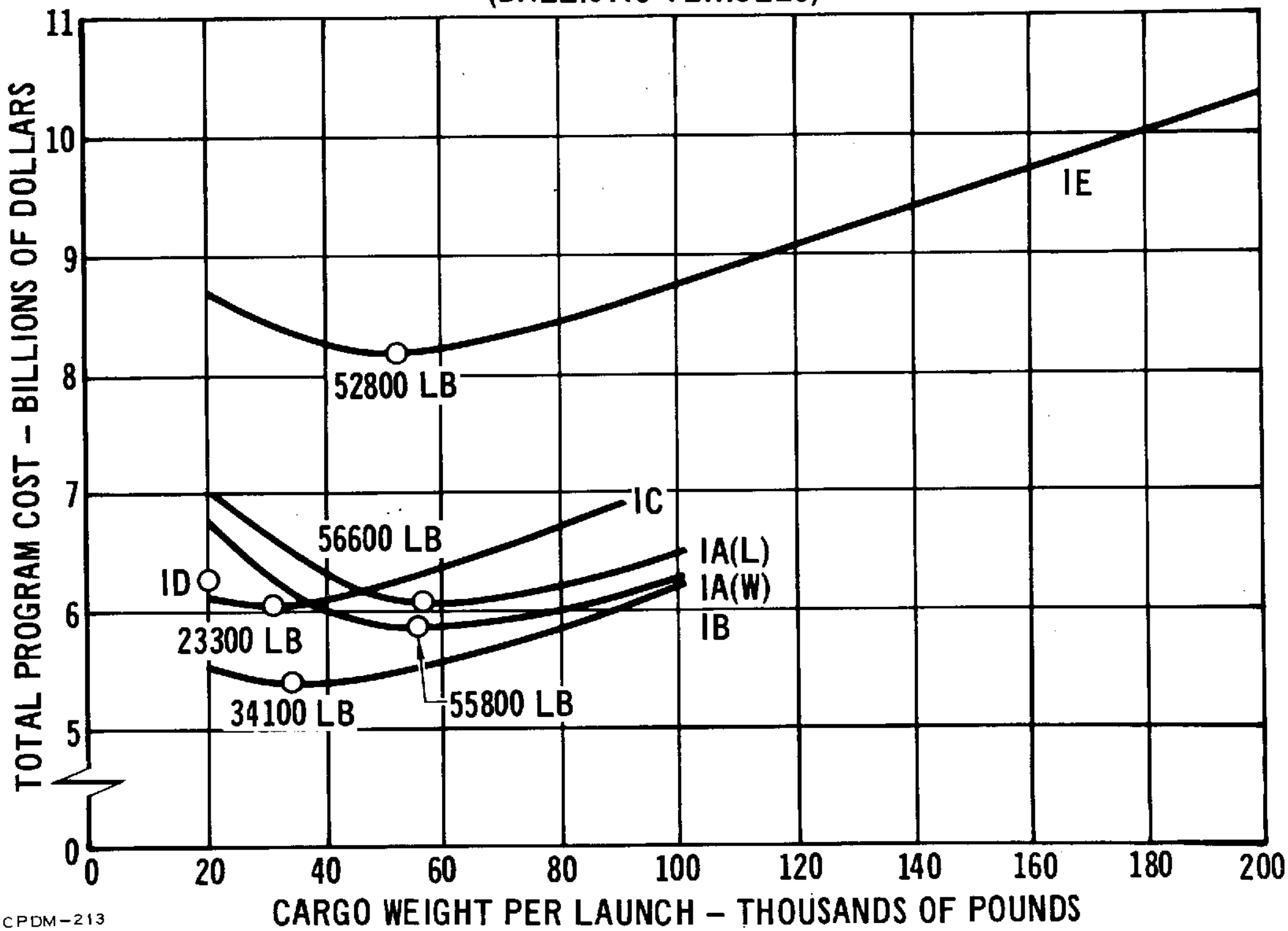
For the IE concept the launch vehicle costs range from 32% to 38% of the total, the sum of the fee and management costs range from 17% to 22% of the total. For the modular concepts, the launch vehicle costs represent from 55-60% of the total with about the same percentage for fee and management.

In general the concepts have a least cost cargo size in the 25,000 to 50,000 lb range and are less sensitive to being slightly oversized than undersized.

The relative costs of the concepts are primarily the result of three interacting factors: the vehicle size, the operations philosophy, and the launch vehicle cost. The IC curve diverges from the IB curve as the cargo weight per launch increases because, for a given cargo weight, the IC is always heavier as a result of the additional heat protection with the accompanying increase in propulsion requirements. This, in turn, requires a larger, more expensive booster, which, combined with the increase in refurbishment cost because of the larger spacecraft size, more than offsets the savings in investment of the cargo/propulsion module.

EFFECT OF CARGO WEIGHT PER LAUNCH ON TOTAL PROGRAM COST

(BALLISTIC VEHICLES)



OCPDM-213

TOP LEVEL COST SUMMARY

(IB Spacecraft)

The cost data are summarized for the modular ballistic concept at the optimum cargo size of 34,100 lbs. Based on the mission success probability this requires 81 launch attempts. Six entry vehicles are purchased in the investment phase, reflecting the effect of the turnaround time. These costs are in millions of dollars.

TOP LEVEL COST SUMMARY

(IB SPACECRAFT–MOD. BALLISTIC)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
SPACECRAFT (S/C)					
ENTRY VEHICLE (E/V)		248.452	119.787		368.269
MISSION MODULE		79.589	308.508		388.097
AGE		162.459	22.980		185.439
LAUNCH FACILITIES		37.629	250.000		287.629
TRAINERS & SIMULATORS		34.731			34.731
SYSTEM INTEGRATION		507.356			507.356
CONTRACT DEFINITION/OPERATIONS	10.702			524.198	534.900
TOTAL BASIC SPACECRAFT	10.702	1070.215	701.275	524.198	2306.390
S/C PROJECT MANAGEMENT	1.070	15.477	3.483		20.031
SUBTOTAL	11.772	1085.692	704.759	524.198	2326.421
S/C FEE	1.177	108.569	70.476	52.420	232.642
SUBTOTAL	12.950	1194.261	775.235	576.618	2559.063
S/C PROGRAM OFFICE MGMT.	1.177	108.569	70.476	52.420	232.642
TOTAL SPACECRAFT	14.127	1302.830	845.710	629.038	2791.705
LAUNCH VEHICLE (L/V)					
BASIC LAUNCH VEHICLE	4.857	485.653	1175.283	473.875	2139.668
L/V FEE	0.486	48.565	117.528	47.388	213.967
SUBTOTAL	5.342	534.218	1292.812	521.263	2353.635
L/V PROGRAM OFFICE MGMT	0.486	48.565	110.712	135.315	295.078
TOTAL LAUNCH VEHICLE	5.828	582.784	1403.524	656.578	2648.713
TOTAL SPACECRAFT & LAUNCH VEH	19.955	1885.614	2249.234	1285.616	5440.419

ENTRY VEHICLE FIRST UNIT COST = 38.402
MISSION MODULE FIRST UNIT COST = 10.425

OCP DM-27 6

TOP LEVEL COST SUMMARY

(IE Spacecraft)

The cost data are summarized for the integral upper stage ballistic concept at the optimum cargo size of 52,800 lbs. Based on the mission success probability, this requires 53 launch attempts. Although the annual launch rate is considerably less than for the modular concepts, the investment phase still required a purchase of six entry vehicles because of the longer turnaround time associated with the larger vehicle. These costs are in millions of dollars.

TOP LEVEL COST SUMMARY

(IE SPACECRAFT – U.S. BALLISTIC)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
SPACECRAFT (S/C)					
ENTRY VEHICLE (E/V)		817.486	388.512		1205.998
MISSION MODULE		0.001	0.002		0.003
AGE		358.204	41.931		400.134
LAUNCH FACILITIES		37.592	250.000		287.592
TRAINERS & SIMULATORS		93.283			93.283
SYSTEM INTEGRATION		1179.214			1179.214
CONTRACT DEFINITION/OPERATIONS	24.858			1135.486	1160.344
TOTAL BASIC SPACECRAFT	24.858	2485.780	680.444	1135.486	4326.568
S/C PROJECT MANAGEMENT	2.486	34.534	3.472		40.491
SUBTOTAL	27.344	2520.313	683.916	1135.486	4367.059
S/C FEE	2.734	252.031	68.392	113.549	436.706
SUBTOTAL	30.078	2772.345	752.307	1249.034	4803.764
S/C PROGRAM OFFICE MANAGEMENT	2.734	252.031	68.392	113.549	436.706
TOTAL SPACECRAFT	32.812	3024.376	820.699	1362.583	5240.470
LAUNCH VEHICLE (L/V)					
BASIC LAUNCH VEHICLE	7.548	754.765	611.277	717.752	2091.342
L/V FEE	0.755	75.476	61.128	71.775	209.134
SUBTOTAL	8.302	830.241	672.405	789.528	2300.476
L/V PROGRAM OFFICE MANAGEMENT	0.755	75.476	265.306	324.263	665.801
TOTAL LAUNCH VEHICLE	9.057	905.718	937.711	1113.791	2966.277
TOTAL SPACECRAFT & LAUNCH VEH	41.869	3930.094	1758.410	2476.374	8206.747
ENTRY VEHICLE FIRST UNIT COST	126.027				
MISSION MODULE FIRST UNIT COST	0.000				

OCPDM-273

EFFECT OF CARGO WEIGHT PER LAUNCH ON TOTAL PROGRAM COST

(Lifting Body Vehicles)

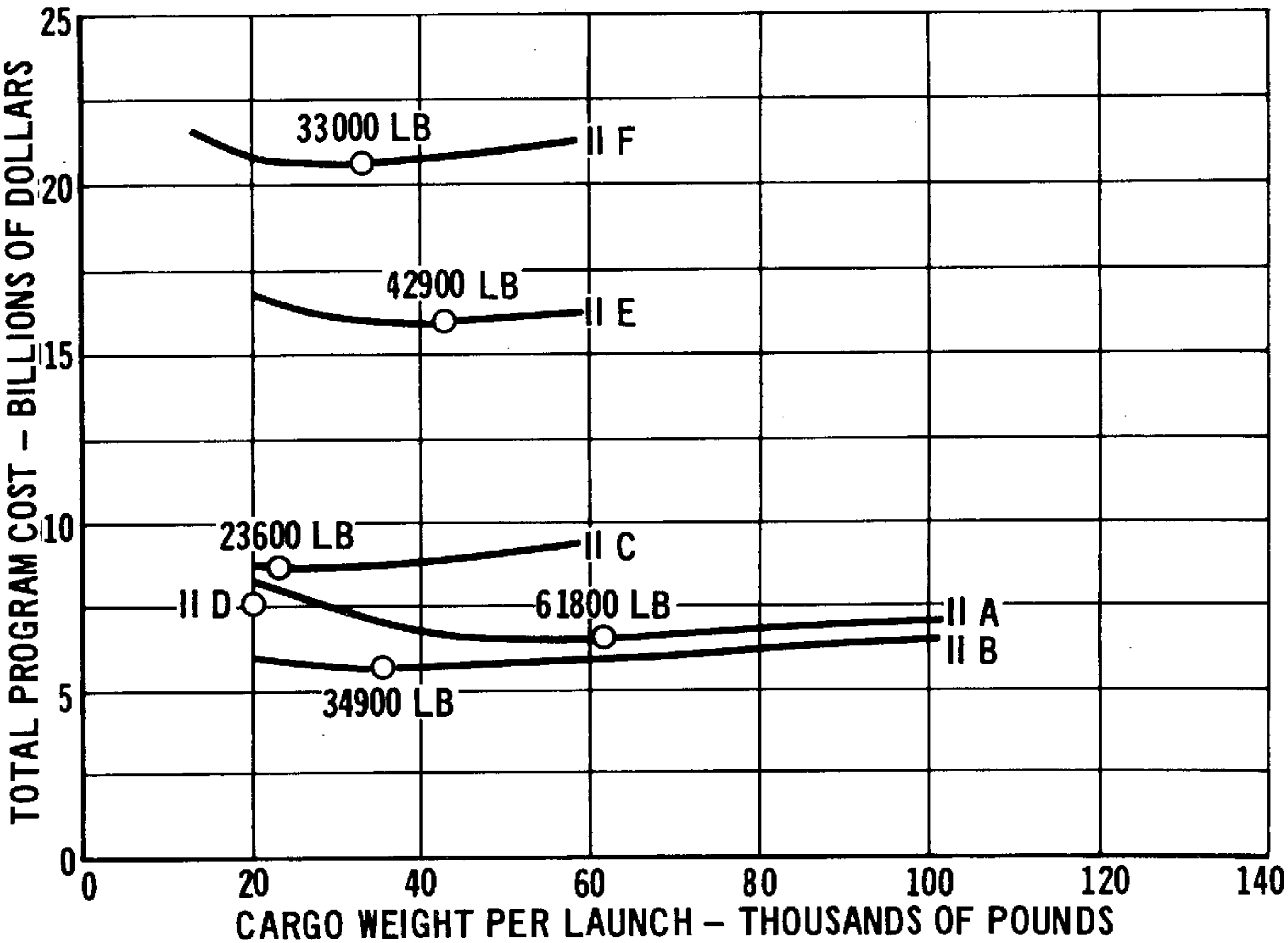
As with the ballistic concepts, these costs are total program costs and include, beside the basic cost, the contractor fee, the prime contractor cost of managing the project segments, and the NASA cost of managing the total program. These data reflect a varying number of vehicles and launches as cargo size varies; therefore as cargo weight per launch is increased and fewer flights are required to support a fixed program the benefits from learning decreases.

For the IIE concept, the launch vehicle costs represent about 28% of the total; for the modular concepts they represent 55 to 60% or about the same percentage as for the ballistic concepts.

The relative costs of the concepts are primarily the result of three interacting factors: the vehicle size, the operations philosophy, and the launch vehicle cost. The size of the IIE configurations, is so large that besides a significant penalty for the expendable launch vheicle, the investment costs actually exceed the investment costs for the B configuration for this size program. It should be pointed out that the IIE configuration is not the most efficient vehicle for an upper stage and therefore, presents an overly pessimistic picture from what might be achieved.

EFFECT OF CARGO WEIGHT PER LAUNCH ON TOTAL PROGRAM COST

LIFTING BODY VEHICLES



OCPDM-214

TOP LEVEL COST SUMMARY

(IIB Spacecraft)

The cost data are summarized for the modular lifting body concept at the optimum cargo size of 34,900 lbs. Based on the mission success probability this requires 78 launch attempts. Six entry vehicles are purchased in the investment phase, reflecting the effect of the turnaround time. These costs are in millions of dollars.

TOP LEVEL COST SUMMARY

(IIB SPACECRAFT – MOD. LIFTING)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
SPACECRAFT (S/C)					
ENTRY VEHICLE		289.936	135.008		424.944
MISSION MODULE		86.585	320.714		407.299
AGE		171.414	24.039		195.454
LAUNCH FACILITIES		40.697	0.0		40.697
TRAINERS & SIMULATORS		40.489			40.489
SYSTEMS INTEGRATION		618.262			618.262
CONTRACT DEFINITION/OPERATIONS	12.474			443.109	455.583
TOTAL BASIC SPACECRAFT	12.474	1247.384	479.761	443.109	2182.727
S/C PROJECT MANAGEMENT	1.247	20.041	3.827		25.115
SUBTOTAL	13.721	1267.424	483.588	443.109	2207.843
S/C FEE	1.372	126.742	48.359	44.311	220.784
SUBTOTAL	15.093	1394.167	531.947	487.420	2428.627
S/C PROGRAM OFFICE MGMT	1.372	126.742	48.359	44.311	220.784
TOTAL SPACECRAFT	16.465	1520.909	580.306	531.730	2649.411
LAUNCH VEHICLE (L/V)					
BASIC LAUNCH VEHICLE	4.978	497.754	1359.174	498.021	2359.927
L/V FEE	0.498	49.775	135.917	49.802	235.993
SUBTOTAL	5.475	547.530	1495.091	547.824	2595.920
L/V PROGRAM OFFICE MGMT	0.498	49.775	118.725	145.108	314.106
TOTAL LAUNCH VEHICLE	5.973	597.305	1613.816	692.932	2910.025
TOTAL SPACECRAFT & LAUNCH VEH	22.439	2118.214	2194.122	1224.662	5559.436

ENTRY VEHICLE FIRST UNIT COST - 47.570
MISSION MODULE FIRST UNIT COST = 11.428

OCPDM-275

TOP LEVEL COST SUMMARY

(IIE Spacecraft)

The cost data are summarized for the integral upper stage lifting body concept at the optimum cargo size of 42,900 lbs. Based on the mission success probability, this requires 64 launch attempts. Eight vehicles must be purchased in the investment phase which is an increase over what was required for the IB or IIB concepts because of the longer turnaround time associated with the larger vehicle. These costs are in millions of dollars.

TOP LEVEL COST SUMMARY

(IIE SPACECRAFT – U.S. LIFTING)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
SPACECRAFT (S C)					
ENTRY VEHICLE (E V)		1649.482	1263.153		2,912.635
MISSION MODULE		2.805	19.404		22.209
AGE		644.149	90.496		734.644
LAUNCH FACILITIES		65.470	250.000		315.470
TRAINERS & SIMULATORS		211.359			211.359
SYSTEM INTEGRATION		2932.751			2932.751
CONTRACT DEFINITION OPERATIONS	55.060			1634.430	1689.490
TOTAL BASIC SPACECRAFT	55.060	5506.015	1623.053	1634.430	8818.559
S C PROJECT MANAGEMENT	5.506	88.921	9.406		103.833
SUBTOTAL	60.566	5594.937	1632.459	1634.430	8922.392
S C FEE	6.057	559.493	163.246	163.443	892.239
SUBTOTAL	66.623	6154.430	1795.705	1797.873	9814.631
S C PROGRAM OFFICE MANAGEMENT	6.057	559.493	163.246	163.443	892.239
TOTAL SPACECRAFT	72.679	6713.923	1958.950	1961.316	10706.870
LAUNCH VEHICLE (L V)					
BASIC LAUNCH VEHICLE	12.430	1243.044	1607.276	1227.192	4089.943
L V FEE	1.243	124.304	160.728	122.719	408.994
SUBTOTAL	13.673	1367.349	1768.004	1349.912	4498.938
L V PROGRAM OFFICE MANAGEMENT	1.243	124.304	480.445	587.211	1193.204
TOTAL LAUNCH VEHICLE	14.917	1491.653	2248.449	1937.123	5692.142
TOTAL SPACECRAFT & LAUNCH VEH	87.596	8205.577	4207.400	3898.439	16399.011

ENTRY VEHICLE FIRST UNIT COST 313.097
MISSION MODULE FIRST UNIT COST 0.780

OCPDM-274

LEVEL 2 COST SUMMARY BY PROGRAM PHASE

(IIE Spacecraft)

The data on the previous chart are shown at the next level of detail which corresponds to Level 5 of the NASA CATF work breakdown structure. The mission module costs shown are for the adapter between the entry vehicle and launch vehicle. The system test hardware costs are based on the hardware requirements as defined in McDonnell Report G975 Volume II Book 2 Section 4.4 and Book 5 Section 6.2.16. These costs are in millions of dollars.

LEVEL 2 COST COST SUMMARY BY PROGRAM PHASE

(IIE SPACECRAFT – U.S. LIFTING)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
SPACECRAFT (S/C)					
ENTRY VEHICLE (E/V)					
THERMAL/STRUCTURE		721.754	673.553		1,395.306
INFLATABLE AERO DEVICES		25.991	20.396		46.387
POWER SUPPLY & ORDNANCE		109.583	54.903		164.486
ECLS		25.866	12.614		38.480
AVIONICS		152.019	44.876		196.896
PROPULSION		614.269	106.621		720 .900
FINAL ASSEMBLY & CHECKOUT			99.330		99.330
SUSTAINING ENGINEERING			88.909		88.909
SUSTAINING TOOLING			47.109		47.109
INITIAL SPARES			114.832		114.832
TOTAL ENTRY VEHICLE		1,649.482	1,263.153		2,912.635
MISSION MODULE					
THERMAL/STRUCTURE		2.805	14.736		17.541
POWER SUPPLY & ORDNANCE		0.0	0.0		0.0
ECLS		0.0	0.0		0.0
AVIONICS		0.0	0.0		0.0
PROPULSION		0.0	0.0		0.0
FINAL ASSEMBLY & CHECKOUT			0.605		0.605
SUSTAINING ENGINEERING			1.224		1.224
SUSTAINING TOOLING			1.075		1.075
INITIAL SPARES			1.764		1.764
TOTAL MISSION MODULE		2.805	19.404		22.209

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LEVEL 2 COST SUMMARY BY PROGRAM PHASE (Cont'd)

(IIE SPACECRAFT – U.S. LIFTING)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
AGE					
NON-RECURRING		173.570			173.570
RECURRING		470.578	90.496		561.074
TOTAL AGE		644.149	90.496		734.644
LAUNCH FACILITIES		65.470	250.000		315.470
TRAINERS & SIMULATORS		211.359			211.359
SYSTEM INTEGRATION					
SYSTEM ENGINEERING		304.786			304.786
SYSTEM TEST OPERATIONS					
AIRDROP TEST		26.633			26.633
GROUND TEST		202.661			202.661
BOOSTED FLIGHT TEST		158.681			158.681
TOTAL SYSTEM TEST OPER		387.975			387.975
SYSTEM TEST HARDWARE					
AIRDROP TEST HARDWARE		63.357			63.357
GROUND TEST HARDWARE					
ENTRY VEHICLE		879.191			879.191
MISSION MODULE		2.329			2.329
TOTAL GROUND TEST HDW		881.520			881.520
BOOSTED FLIGHT HARDWARE					
ENTRY VEHICLE		1,258.805			1,258.805
MISSION MODULE		3.097			3.097
TOTAL BOOST FLT HDW		1,261.901			1,261.901
TOTAL SYS TEST HDW		2,206.779			2,206.779

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LEVEL 2 COST SUMMARY BY PROGRAM PHASE (Cont'd)

(IIE SPACECRAFT – U.S. LIFTING)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
MOCKUPS		33.211			33.211
TOTAL SYSTEM INTEGRATION		2,932.751			2,932.751
OPERATIONS PHASE (S C)					
LAUNCH OPERATIONS				202.143	202.143
LAUNCH AREA SUPPORT				154.620	154.620
MISSION CONTROL SUPPORT				14.550	14.550
AGE MAINTENANCE				17.242	17.242
FACILITY MAINTENANCE				8.410	8.410
RECOVERY OPERATIONS				29.230	29.230
RECERTIFICATION				1,175.733	1,175.733
TRANSPORTATION				8.704	8.704
TECHNICAL SUPPORT				23.798	23.798
TOTAL OPERATIONS PHASE				1,634.430	1,634.430

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LEVEL 2 COST SUMMARY BY PROGRAM PHASE (Cont'd)

(IIE SPACECRAFT – U.S. LIFTING)

	CONTRACT DEFINITION	RDT&E PHASE	INVESTMENT PHASE	OPERATIONAL PHASE	TOTAL PROGRAM
CONTRACT DEFINITION	55.060				55.060
TOTAL BASIC SPACECRAFT	55.060	5,506.015	1,623.053	1,624.430	8,818.559
S/C PROJECT MANAGEMENT	5.506	88.921	9.406		103.833
SUBTOTAL	60.566	5,594.937	1,632.459	1,634.430	8,922.392
S/C FEE	6.057	559.492	162.246	163.443	892.239
SUBTOTAL	66.623	6,154.430	1,795.705	1,797.873	9,814.631
S/C PROGRAM OFFICE MGMT	6.057	559.493	163.246	163.443	892.239
TOTAL SPACECRAFT	72.679	6,713.923	1,958.950	1,961.316	10,706.870
LAUNCH VEHICLE (L/V)					
BASIC LAUNCH VEHICLE	12.430	1,243.044	1,607.276	1,227.192	4,089.943
L/V FEE	1.243	124.304	160.728	122.719	408.994
SUBTOTAL	13.673	1,367.349	1,768.004	1,349.912	4,498.938
L/V PROGRAM OFFICE MGMT	1.243	124.304	480.445	587.211	1,193.204
TOTAL LAUNCH VEHICLE	14.917	1,491.653	2,248.449	1,937.123	5,692.142
TOTAL SPACECRAFT & LAUNCH VEH	87.596	8,205.577	4,207.400	3,898.439	16,399.011

ENTRY VEHICLE FIRST UNIT COST = 313.097
MISSION MODULE FIRST UNIT COST = 0.780

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TOP LEVEL RDT&E COST SUMMARY BY LABOR CATEGORY

(IIE Spacecraft)

These data summarize the RDT&E costs of the previous charts by labor category. The cost data organized in this manner can also be printed out at lower levels of detail. These costs are in millions of dollars.

TOP LEVEL RDTE COST SUMMARY BY LABOR CATEGORY

(IIE SPACECRAFT – U.S. LIFTING)

	ENGINEERING LABOR	TOOLING LABOR	PRODUCTION LABOR	MATL, CFE SUBCONT	REMOTE SITE & CUSTOMER	TOTAL PROGRAM
RDT & E PHASE						
SPACECRAFT						
ENTRY VEHICLE	606.162	314.494		728.826		1649.482
MISSION MODULE	1.889	0.852		0.064		2.805
SUBTOTAL	608.052	315.346		728.889		1652.287
AGE	129.766		238.114	276.268		644.149
LAUNCH FACILITIES				61.125	4.345	65.470
TRAINERS & SIMULATORS	27.208	0.0	25.310	158.841		211.359
SYSTEM ENGINEERING	304.026			0.760		304.786
SYSTEM TEST OPERATIONS						
AIR DROP TEST				4.711	21.922	26.633
GROUND TEST	86.367			54.301	61.993	202.661
BOOSTED FLIGHT TEST				55.367	103.314	158.681
TOTAL SYS TEST OPER	86.367			114.379	187.229	387.975
SYSTEM TEST HARDWARE						
AIRDROP HDW	31.772	4.394	15.266	11.926		63.357
GROUND TEST HDW						
ENTRY VEHICLE	67.809	18.244	474.099	319.039		879.191
MISSION MODULE	0.212	0.079	1.931	0.108		2.329
TOTAL GRD TEST HDW	68.201	18.323	476.030	319.147		881.520

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TOP LEVEL RDTE COST SUMMARY BY LABOR CATEGORY (Cont'd)

(IIE SPACECRAFT – U.S. LIFTING)

	ENGINEERING LABOR	TOOLING LABOR	PRODUCTION LABOR	MATL, CFE SUBCONT	REMOTE SITE & CUSTOMER	TOTAL PROGRAM
BOOSTED FLIGHT HDW						
ENTRY VEHICLE AVE	148.008	49.726	451.803	399.467		1049.004
MISSION MODULE AVE	0.463	0.214	1.784	0.120		2.581
TOTAL BOOST FLT AVE	148.471	49.940	453.587	399.586		1051.585
ENTRY VEHICLE SPARES			129.907	79.893		209.801
MISSION MODULE SPARES			0.492	0.024		0.516
TOTAL SPARES			130.400	79.917		210.317
TOTAL BOOST FLT HDW	148.471	49.940	583.987	479.504		1261.901
TOTAL SYSTEM TEST HDW	248.264	72.657	1075.282	810.576		2206.779
MOCKUPS	5.756		25.310	2.145		33.211
TOTAL SYSTEMS INTEGRATION	644.412	72.657	1100.592	927.860	187.229	2932.751
TOTAL BASIC SPACECRAFT	1409.439	388.003	1364.017	2152.983	191.574	5506.015
S/C PROJECT MANAGEMENT	84.687			4.234		88.921
SUBTOTAL	1494.126	388.003	1364.017	2157.217	191.574	5594.937
S/C FEE						559.493
SUBTOTAL						6154.430
S/C PROGRAM OFFICE MGMT						559.493
TOTAL SPACECRAFT						6713.923

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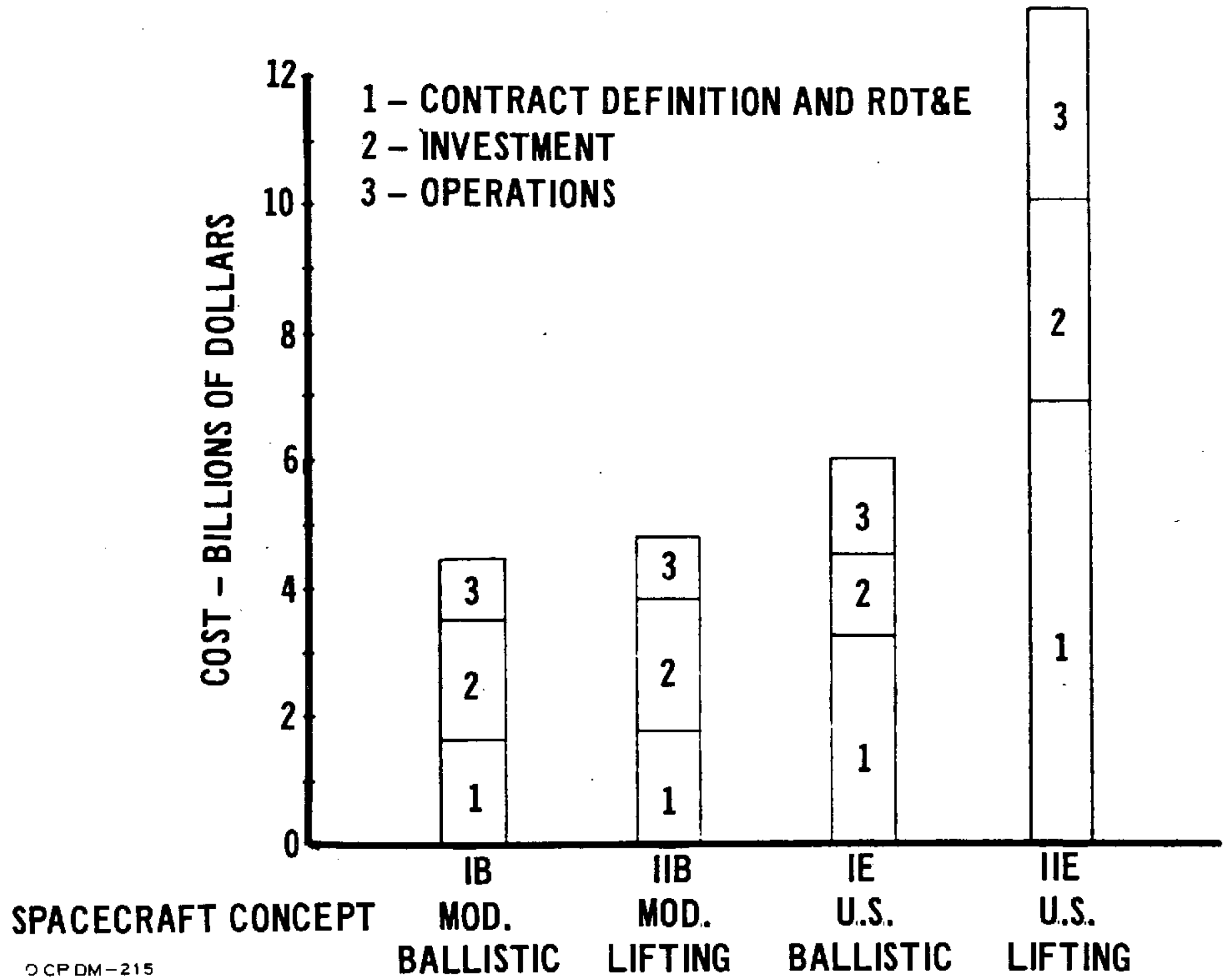
BASIC SPACECRAFT AND LAUNCH VEHICLE COST BY PROGRAM PHASE

The basic spacecraft plus launch vehicle costs are broken down by program phase. As would be expected, the investment cost is a smaller percentage of the total for the reusable upper stage vehicle and drops from about 40% to about 20%. Likewise, the operations costs for the integral vehicles is a larger percentage because the vehicles are larger and require more refurbishment under the study groundrules.

BASIC SPACECRAFT AND LAUNCH VEHICLE COST BY PROGRAM PHASE



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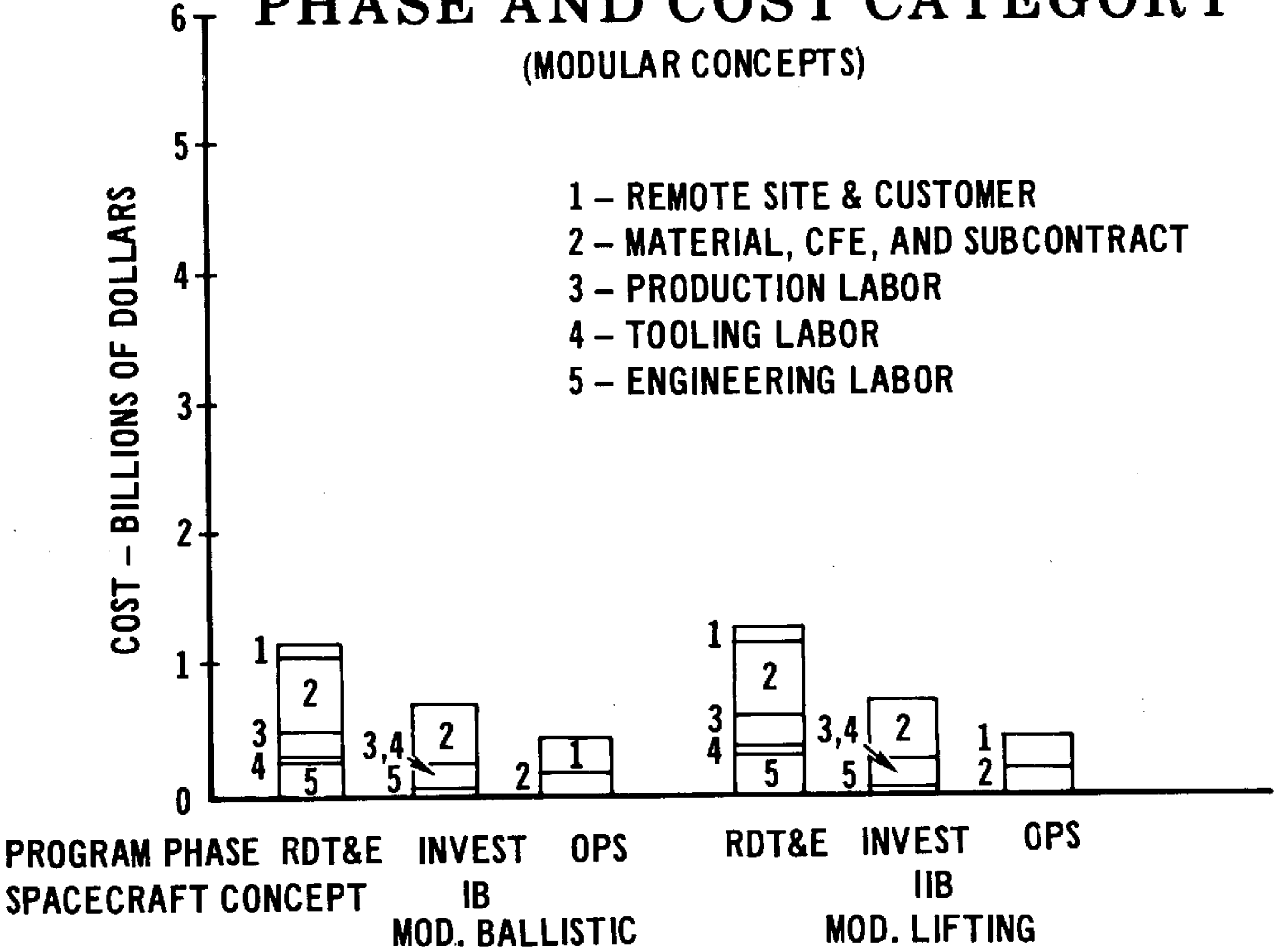
BASIC SPACECRAFT COST BY PROGRAM PHASE AND COST CATEGORY

These charts further break down the costs within each mission phase by cost category. It should be noted that this figure shows basic spacecraft costs only and does not include the launch vehicle. The percent contribution to the total cost by each cost category is not greatly affected by either configuration or by reuse concept.

BASIC SPACECRAFT COST BY PROGRAM PHASE AND COST CATEGORY

(MODULAR CONCEPTS)



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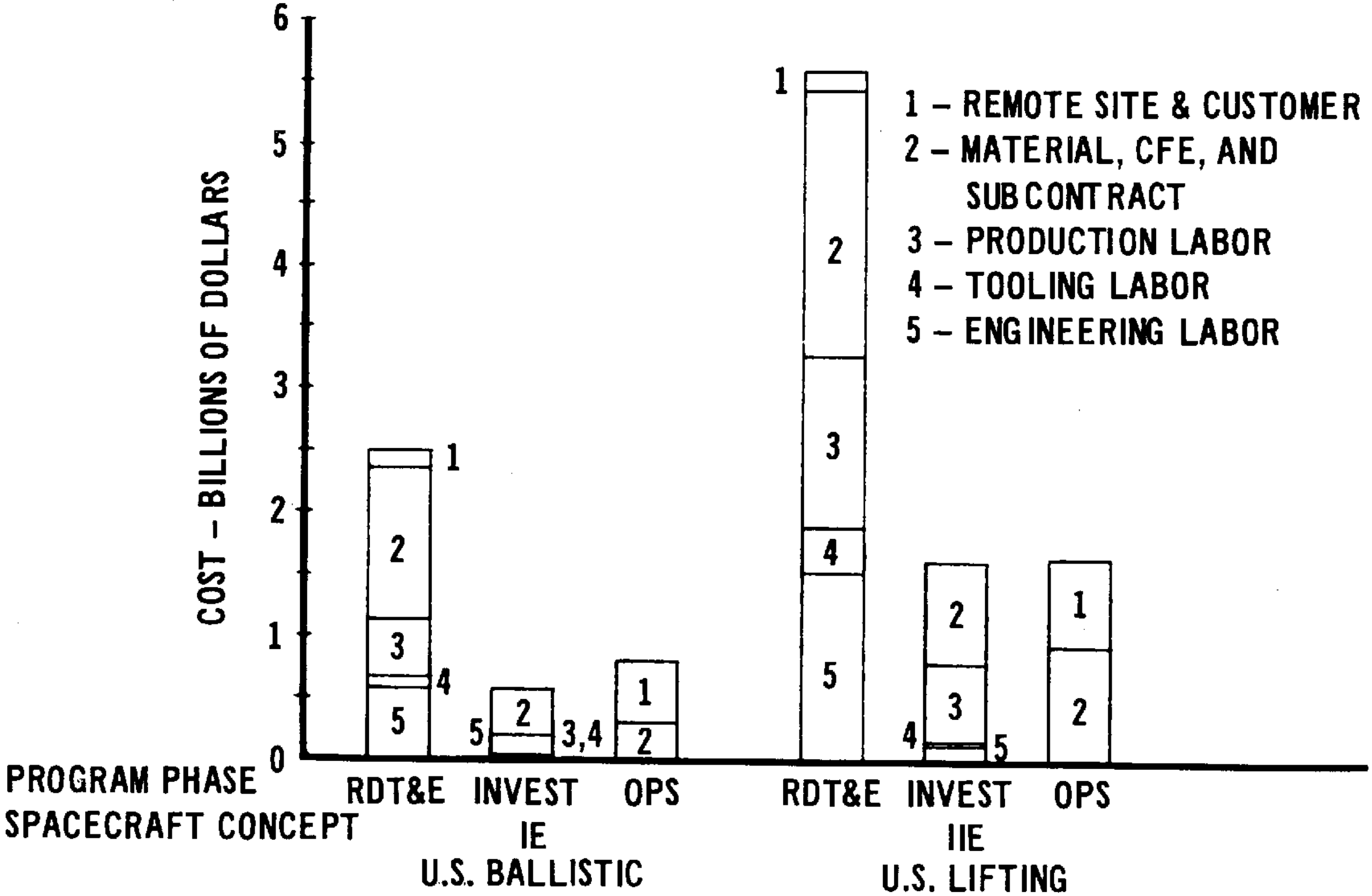
BASIC SPACECRAFT COST BY PROGRAM PHASE AND COST CATEGORY

(INTEGRAL UPPER STAGE)



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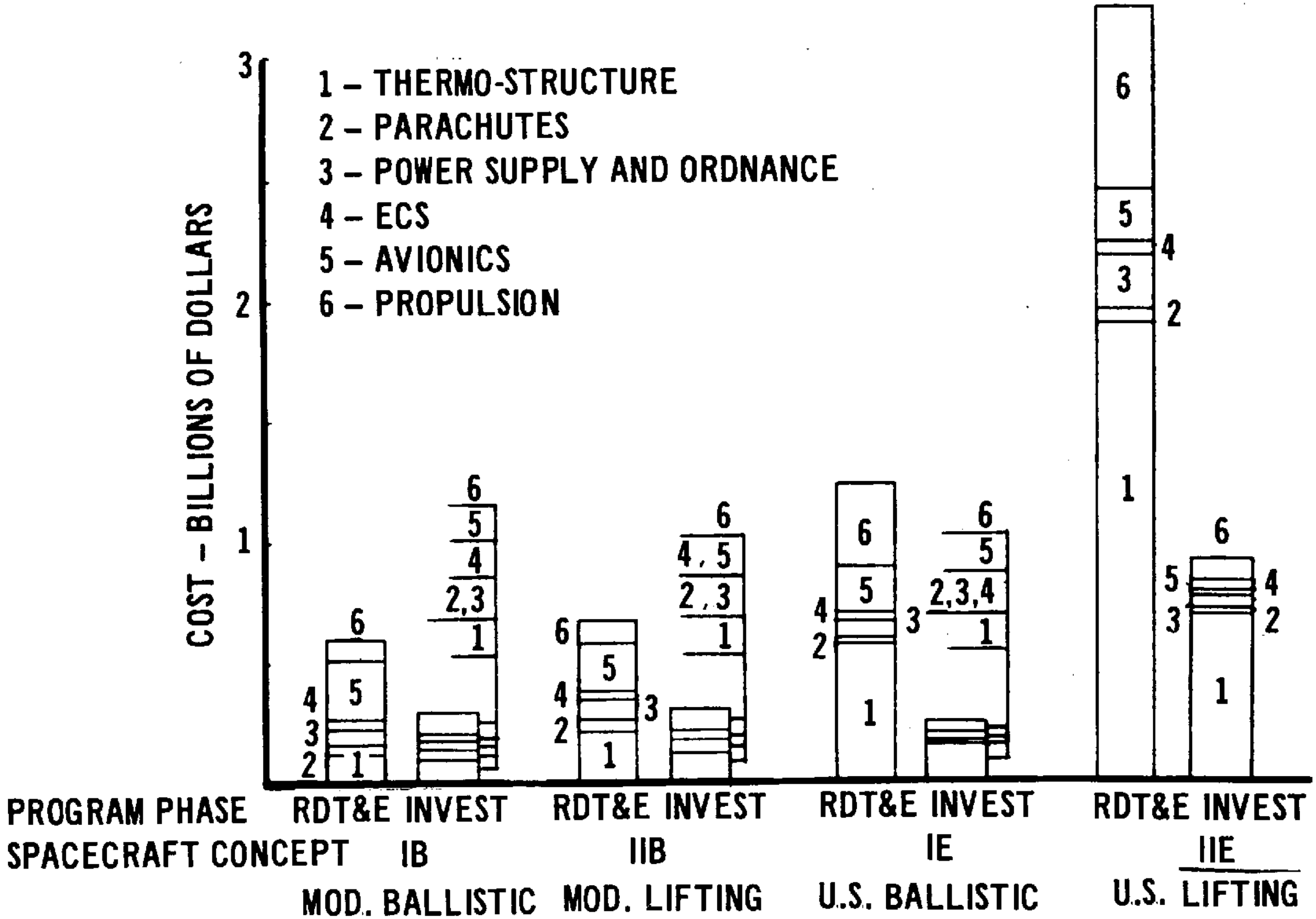
SUBSYSTEM COST BY PROGRAM PHASE

The spacecraft subsystem costs are broken down by program phase. For the modular vehicles, both the entry vehicle and mission module costs are included. The avionics and ECS are nearly fixed cost regardless of configuration or reuse concept; the avionics because it is largely dependent upon mission and the ECS because of its dependence upon crew size. The thermo structure costs vary both with configuration and reuse category; with configuration because of the efficiency of the shape, and with reuse category because of the vehicle size.

Note that the avionics dominate the cost for the small vehicles but that both structure and propulsion are considerably larger for a reusable upper stage. In fact structure represents from 60-70% of the total cost.

SUBSYSTEM COSTS BY PROGRAM PHASE



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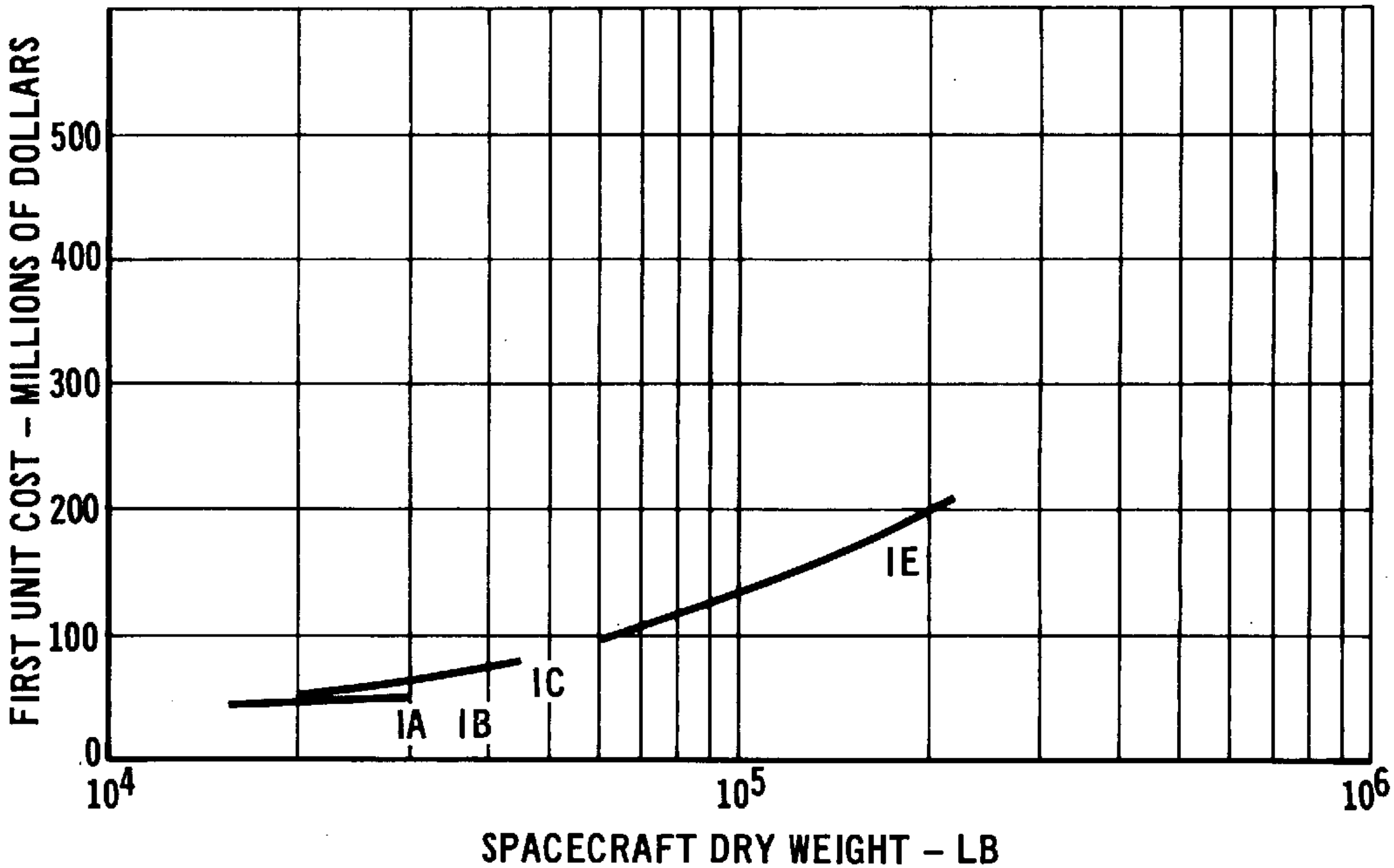
BALLISTIC SPACECRAFT FIRST UNIT COSTS

First unit costs for the ballistic vehicle indicate a continuous trend with dry weight in going from a vehicle which has only the mission module integral (C) to a reusable upper stage. As with development costs, the thermo-structure begins to dominate as the dry weight increases.

BALLISTIC SPACECRAFT FIRST UNIT COSTS

NOTE: DRY WEIGHT FOR CONCEPTS A AND B INCLUDES BOTH ENTRY VEHICLE AND MISSION MODULE



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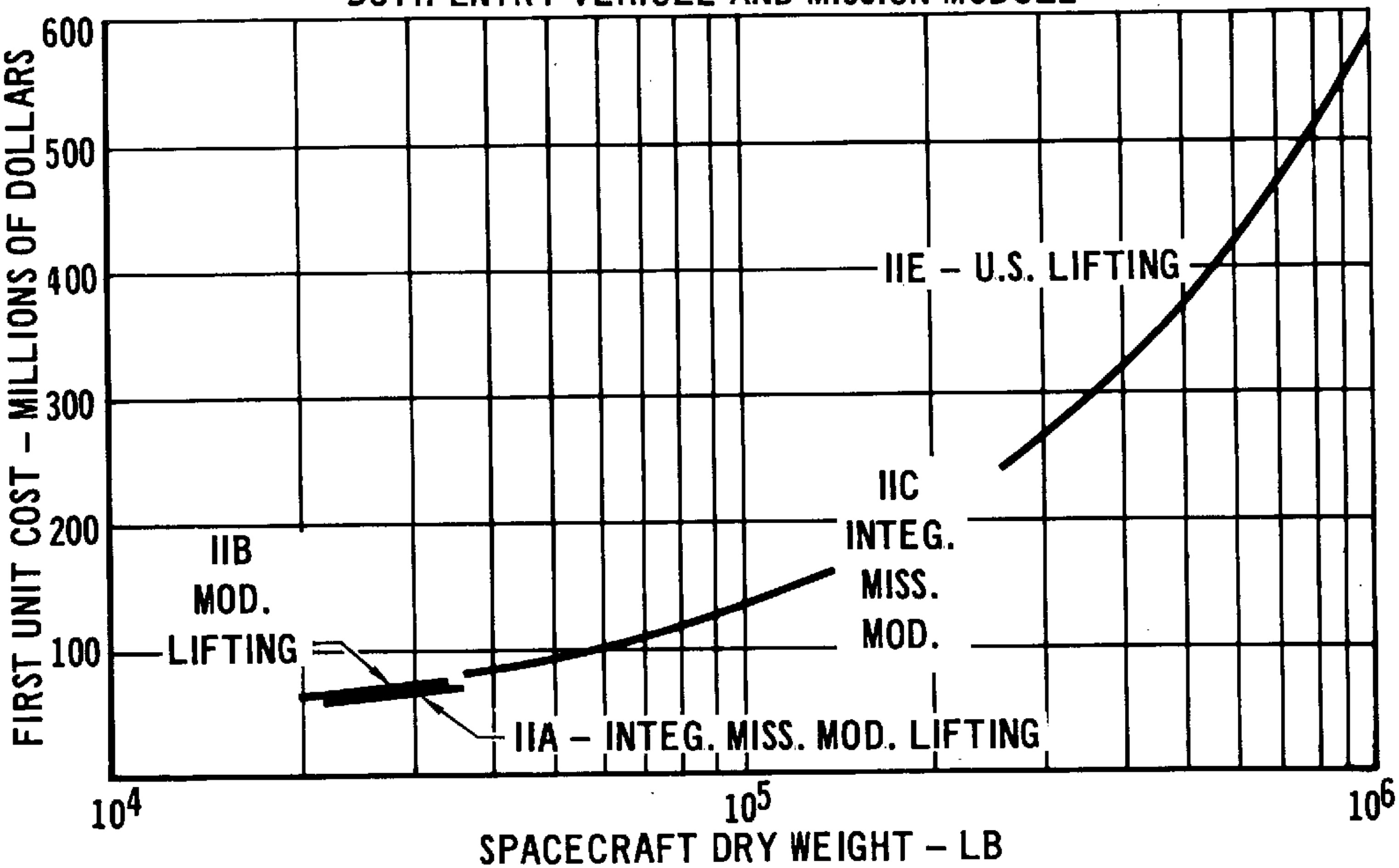
LIFTING BODY SPACECRAFT FIRST UNIT COSTS

The lifting body spacecraft costs follow trends similar to those of the ballistic vehicles. In fact if data for the two spacecraft are overlaid, they lie on top of each other. It should be noted that these trends are for two types of spacecraft (ballistic and lifting) and cover a spectrum of reuse categories from modular to integral upper stage. However, caution should be exercised in applying these costs to other spacecraft which may have different shapes, use advanced materials, etc. These kinds of changes could shift the data and were not investigated in this study.

LIFTING BODY SPACECRAFT FIRST UNIT COSTS

NOTE: DRY WEIGHT FOR CONCEPTS A AND B INCLUDES BOTH ENTRY VEHICLE AND MISSION MODULE



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PRIMARY STRUCTURE ALTERNATES

The dry weight and gross weight data are shown for several of the primary structure alternates of the reusable upper stage vehicles. The cargo size for the IE concept is 52,800 lbs. and for the II E is 42,900 lbs.

PRIMARY STRUCTURE ALTERNATES

SPACECRAFT CONCEPT	STRUCTURE CONCEPT	DRY WEIGHT (LB)	W_G (LB)	MATERIAL	CONSTRUCTION
IE	1	112,809	640,981	ALUMINUM	SINGLE SKIN
	2	91,281	555,284	ALUMINUM	SHEET STRINGER
U.S.	3	90,669	552,854	ALUMINUM	CORRUGATIONS
BALLISTIC	5	90,791	553,379	MAGNESIUM	SHEET STRINGER
	8	82,129	518,718	TITANIUM	SHEET STRINGER
	11	106,625	616,671	STEEL	SHEET STRINGER
IIE	1	465,387	1,946,018	ALUMINUM	SINGLE SKIN
	2	379,490	1,624,073	ALUMINUM	SHEET STRINGER
	3	374,320	1,605,040	ALUMINUM	CORRUGATIONS
U.S.	5	312,448	1,368,895	MAGNESIUM	SHEET STRINGER
LIFTING)	8	361,071	1,554,850	TITANIUM	SHEET STRINGER

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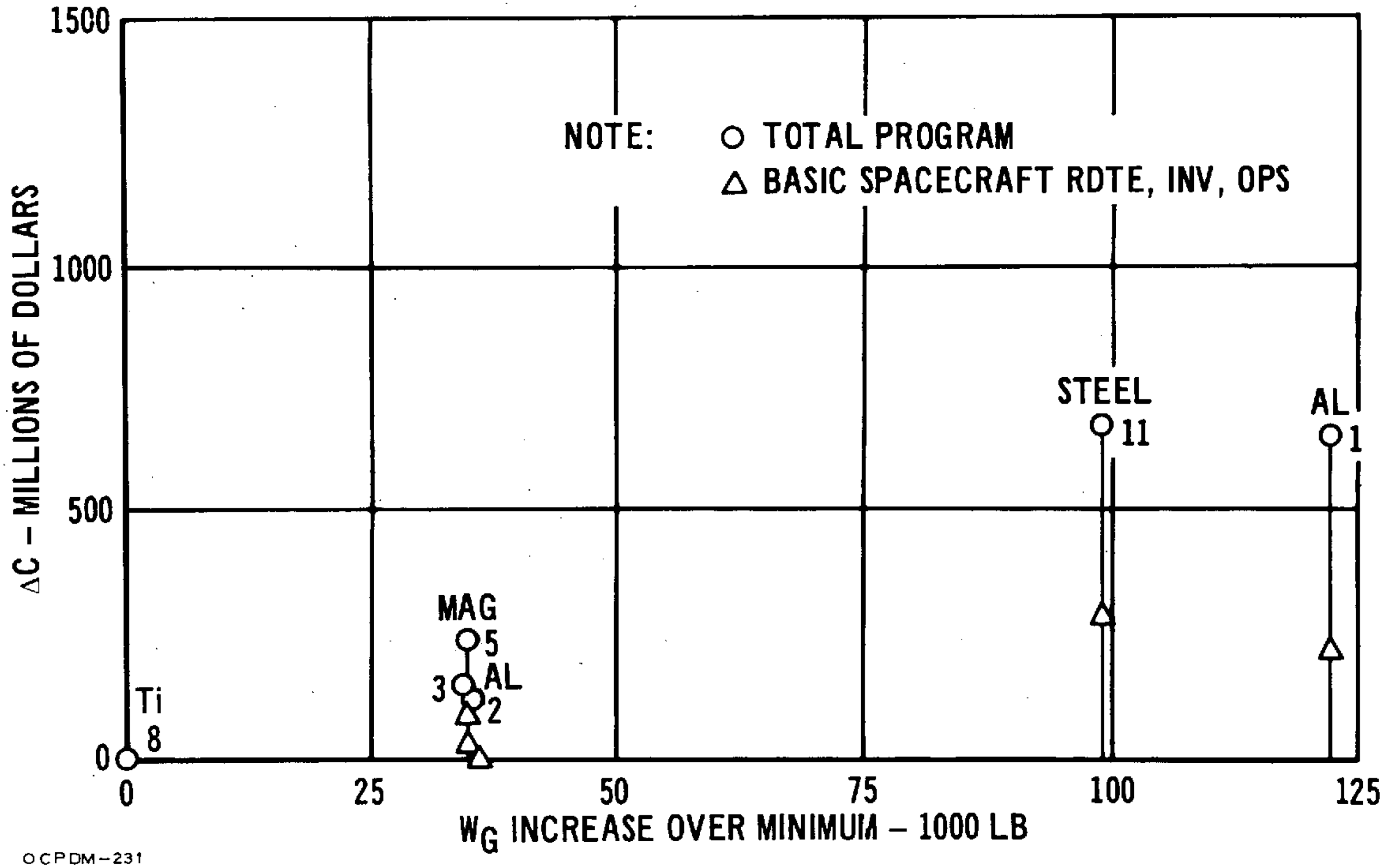
COST-WEIGHT TRENDS OF PRIMARY STRUCTURE ALTERNATES

(IE Spacecraft)

The least cost approach for the reusable ballistic upper stage is the titanium which also happens to be the least weight. It should be noted that the spacecraft cost for the aluminum is the same as for the titanium and that the cost increment results from the increased launch vehicle costs because of the increased weight.

COST-WEIGHT TRENDS OF PRIMARY STRUCTURE ALTERNATES

(IE SPACECRAFT – U.S. BALLISTIC)



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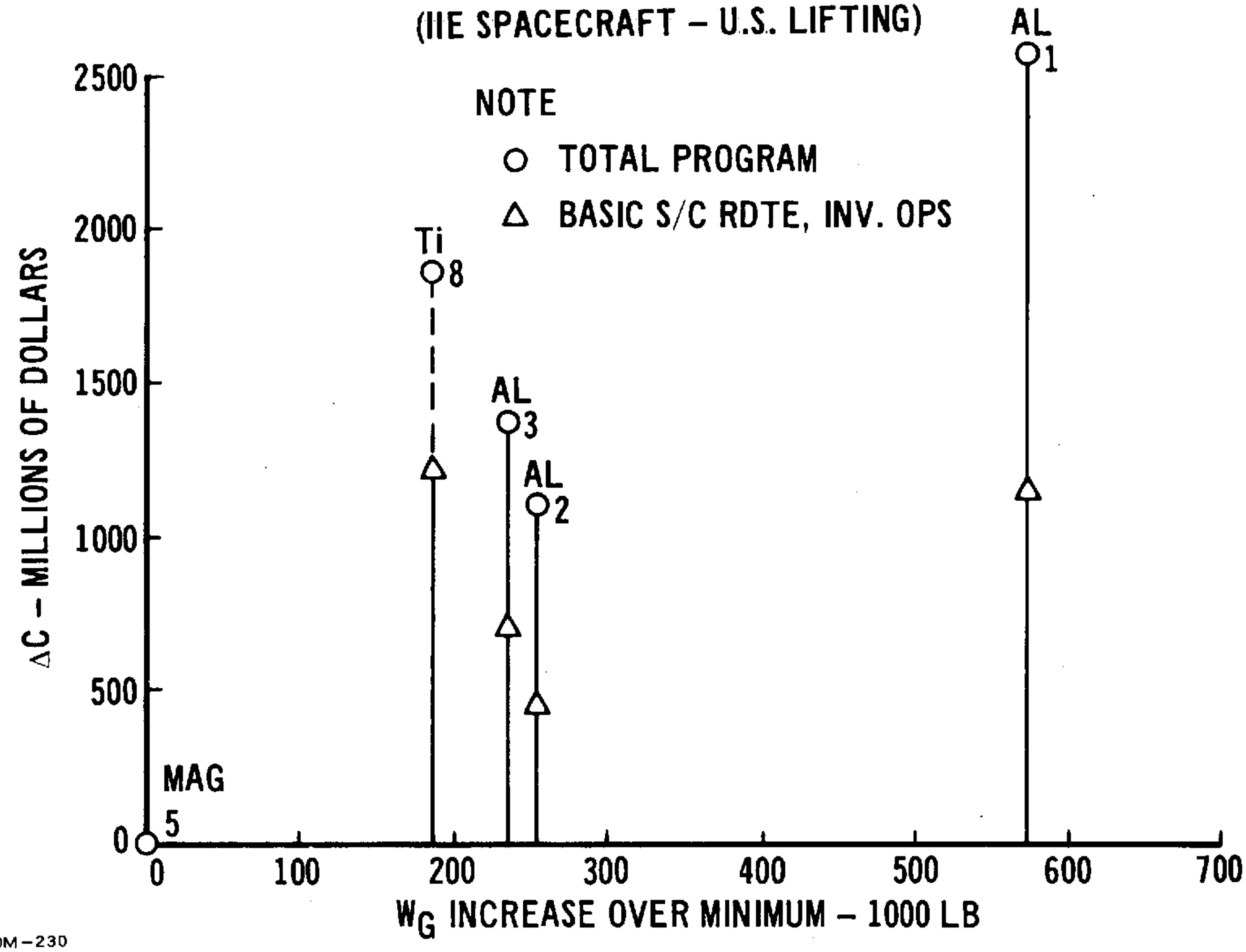
COST-WEIGHT TRENDS OF PRIMARY STRUCTURE ALTERNATES
(IIE Spacecraft)

The least cost approach for the reusable lifting body upper stage is the magnesium with titanium being next to the highest. The reason for the trends shown here are that the frames for the M2-F2 shape are very thick and frame weight becomes the dominant factor. In determining frame thickness the only parameter directly affected by the material selection is $(E/F_{cy})^{0.279}$. Even though titanium results in the thinnest gauges (compared to aluminum and magnesium), the difference is not enough to offset the effect of the density.

Another trend shown on this chart is that least weight is not necessarily the least cost. If concept 8 (titanium) is compared to concept 2 or 3 (aluminum) it can be seen that a 50,000 to 70,000 lb weight penalty can be accepted and still realize a considerable saving. This saving all results from the spacecraft since the launch vehicle costs went up with the increased weight.

COST-WEIGHT TRENDS OF PRIMARY STRUCTURE ALTERNATES

(IIE SPACECRAFT – U.S. LIFTING)



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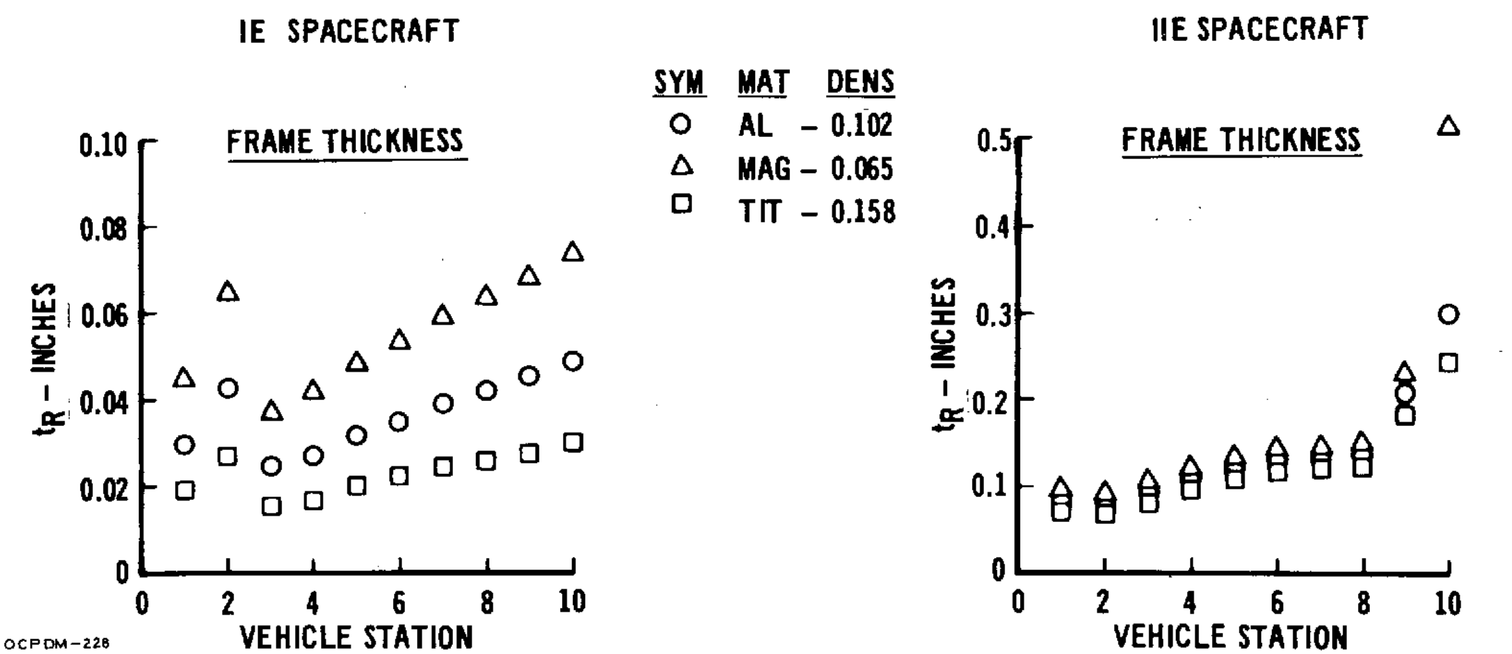
EFFECT OF FRAMES ON MATERIAL SELECTION

The sizing model examines the loads on the spacecraft in ten sections and determines skin and frame thicknesses for each section separately. The only parameter that varies with material for the ballistic vehicles is $1/F_{tu}$ and it can be seen that the frame thicknesses at a given station varies in the ratio of $1/F_{tu}$ for the various materials.

Because of the shape of the M2-F2 the frames are designed by $(E/F_{cy})^{0.279}$ and it can be seen that the thickness varies with this parameter for the various materials. Although titanium would give the lightest shell weight it is more than offset by the frame weight.

EFFECT OF FRAMES ON MATERIAL SELECTION

	IE SPACECRAFT – U.S. BALLISTIC			IIE SPACECRAFT – U.S. LIFTING		
	AL	MAG	TIT	AL	MAG	TIT
SHELL WT/FRAME WT	1.6	1.6	1.1	0.48	0.62	0.21
SHELL WT/AL SHELL WT	1.0	0.942	0.636	1.0	0.825	0.670
FRAME WT/AL FRAME WT	1.0	0.956	0.933	1.0	0.636	1.482
TOTAL SHELL & FRAME WT/TOTAL AL	1.0	0.946	0.749	1.0	0.697	1.220



OCPDM-228

ORBIT MANEUVER ALTERNATES

(IIB Spacecraft)

The dry weight and gross weight data are shown for each of the orbital maneuver alternates for the modular lifting body spacecraft. These data are shown for the optimum cargo size of 34,900 pounds.

ORBITAL MANEUVER ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)

ORBITAL MANEUVER CONCEPTS	W_{DRY} (LB)	W_G (LB)	ATTITUDE CONTROL SEPARATE	O_2/H_2 ENGINE	DEORBIT
1	22,769	71,661	NO	NO	LIQUID (NTO/MMH)
2	23,222	72,195	YES	NO	LIQUID (NTO/MMH)
3	22,359	68,990	NO	YES	LIQUID (O_2/H_2)
4	22,745	69,436	YES	YES	LIQUID (O_2/H_2)
5	22,830	71,936	NO	NO	SOLID
6	23,280	72,467	YES	NO	SOLID
7	22,578	69,757	NO	YES	SOLID
8	22,969	70,208	YES	YES	SOLID

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ORBIT MANEUVER COMPARISON

Some of the type of comparisons of the alternate orbital maneuver concepts are indicated. The data for the various concepts are shown on the following chart.

ORBITAL MANEUVER COMPARISONS

EFFECT OF LIQUID VS SOLID DEORBIT	1–5	NTO/MMH–SOLID
	2–6	NTO/MMH–SOLID
	3–7	O_2/H_2 – SOLID
	4–8	O_2/H_2 – SOLID
EFFECT OF SEPARATE ATTITUDE CONTROL ENGINES – NO VS YES	1–2	
	3–4	
	5–6	
	7–8	
EFFECT OF NTO/MMH VS O_2/H_2	1–3	
	2–4	
	5–7	
	6–8	

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COST-WEIGHT TRENDS OF ORBIT MANEUVER ALTERNATES

(IIB Spacecraft)

Although concept 3 results in the least weight for the modular lifting body spacecraft, it does not result in the least cost. The least cost system actually has a gross weight penalty of about 2700 pounds.

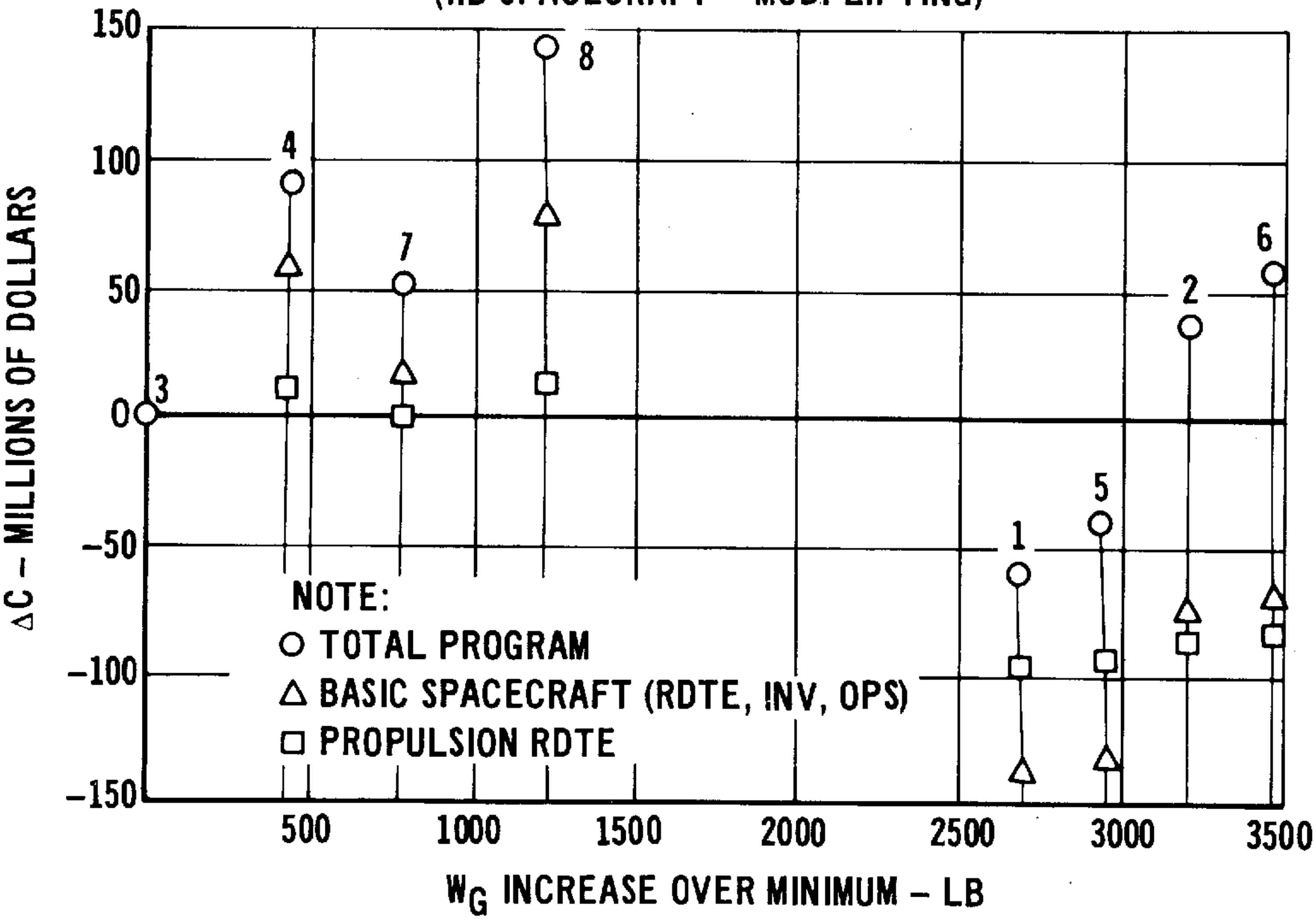
Liquid propulsion for deorbit consistently shows a cost advantage over solids with a total program saving of from $20 to $50 million for the baseline program requirements of 2.5M pounds of cargo in ten years.

Separate attitude control engines do not pay off because the extra weight and development cost are too large to be offset by the slightly improved moment arm and resulting efficiency that can be achieved.

Although O_2/H_2 can save 2000-3000 pounds of weight, the velocity requirements of the modular spacecraft are so small that the development cost of the higher performance engine can not be justified.

COST-WEIGHT TRENDS OF ORBITAL MANEUVER ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)



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ORBIT MANEUVER ALTERNATES

(IIE Spacecraft)

The dry weight and gross weight data are shown for each of the orbital maneuver alternates of the reusable upper stage lifting body spacecraft. These data are shown for the optimum cargo size of 42,900 pounds.

ORBITAL MANEUVER ALTERNATES

(IIE SPACECRAFT – U.S. LIFTING)

ORBITAL CONCEPT	W_{DRY} (LB)	W_G (LB)	ATTITUDE CONTROL SEPARATE	O_2/H_2 ENGINE	DEORBIT
2	379,490	1,624,073	YES	NO	LIQUID (NTO/MMH)
4	308,595	1,293,721	YES	YES	LIQUID (O_2/H_2)
6	388,284	1,673,615	YES	NO	SOLID
8	354,785	1,504,502	YES	YES	SOLID

OCPDM–236

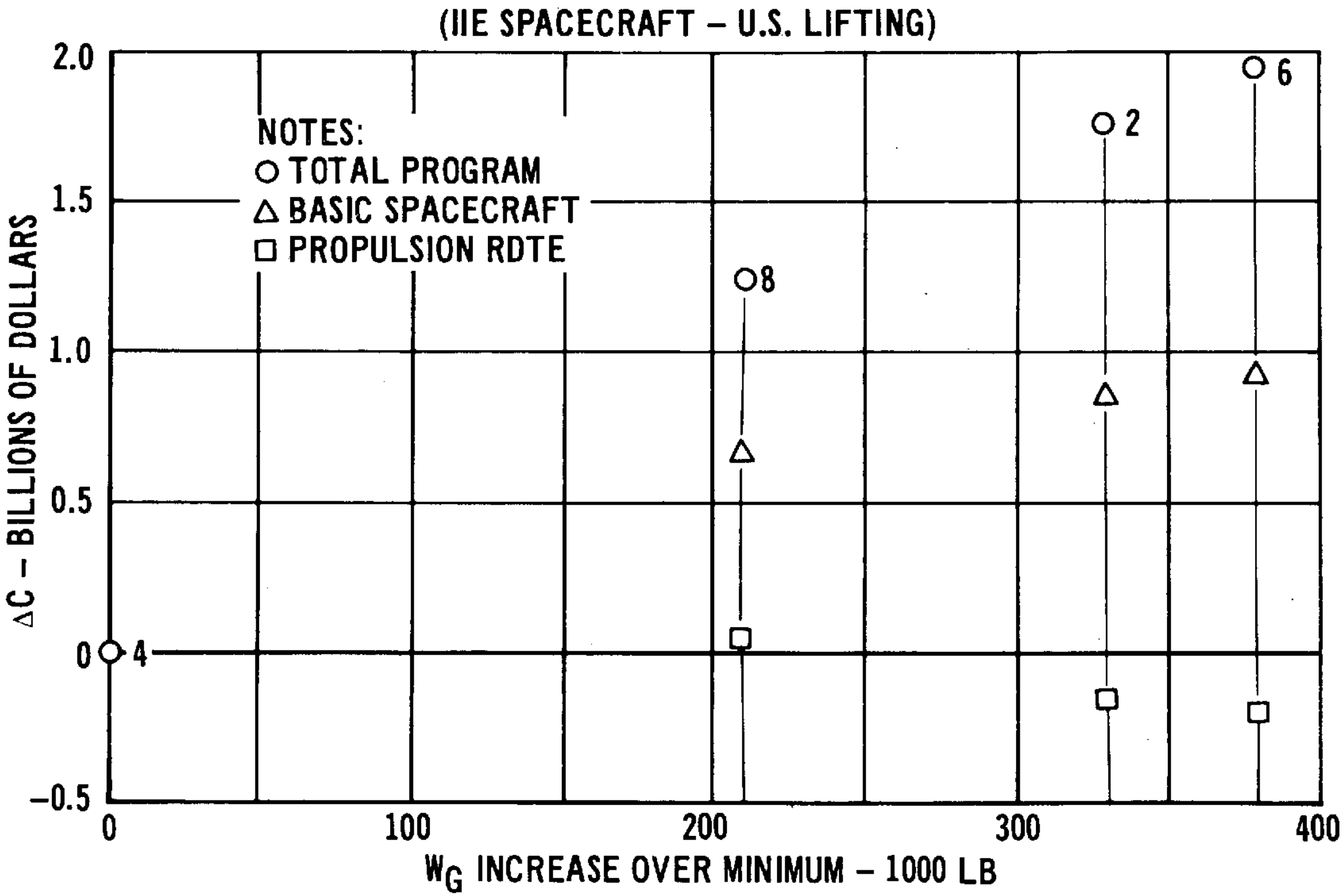
COST WEIGHT TRENDS OF ORBIT MANEUVER ALTERNATES

(IIE Spacecraft)

For the large reusable upper stage, the orbital maneuver alternate vehicle which gives the least weight also gives the least total program cost. This is not the least cost propulsion concept, since either concept 2 or 6 would save about $200 million in the propulsion development. However for the large vehicle, the increased performance shows a definite cost advantage.

If a solid deorbit was considered a requirement for reliability, the cost penalty would be about $1.2 billion. The actual propulsion RDT&E cost increase is insignificant but the spacecraft size has increased significantly (the dry weight increase is $\sim$ 46,000 pounds), increasing the spacecraft cost and launch vehicle cost about $600 million each.

COST WEIGHT TRENDS OF ORBITAL MANEUVER ALTERNATES



OCPDM–237

ENVIRONMENTAL CONTROL SYSTEM ALTERNATES

(IIB Spacecraft)

The dry weight and gross weight data are shown for each of the ECS alternates for the modular lifting body spacecraft. Three basic variations are considered: the method of oxygen storage; the location of the oxygen; and the choice of using a radiator on the mission module to reject heat in addition to using a water boiler.

ENVIRONMENTAL CONTROL SYSTEM ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)

ENVIRONMENTAL CONTROL SYSTEM CONCEPT	W_{DRY} (LB)	W_G (LB)	O_2 STORAGE	EQUIPMENT LOCATION	
				O_2	RAD
1	22,082	70,996	GAS	MM	MM
4	22,016	71,533	GAS	MM	NONE
5	21,855	71,348	CRYO	MM	NONE
6	21,951	71,516	CRYO	EV	NONE
7	21,914	70,798	CRYO	MM	MM
8	21,998	70,949	CRYO	EV	MM

NOTE: ALL CONCEPTS HAVE A WATER BOILER AND LiOH CANISTER IN EV.

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ENVIRONMENTAL CONTROL SYSTEM COMPARISONS

(IIB Spacecraft)

Some of the type comparisons of the alternate ECS concepts are indicated. The data for the various concepts are shown on the following chart.

ENVIRONMENTAL CONTROL SYSTEM COMPARISONS

(IIB SPACECRAFT – MOD. LIFTING)

EFFECT OF WB/RAD VS WB (GAS)	1–4
EFFECT OF WB/RAD VS WB (CRYO)	8–6
EFFECT OF GAS VS CRYO (WB/RAD)	1–7
EFFECT OF O_2 IN MM VS EV (CRYO, WB)	5–6
EFFECT OF O_2 IN MM VS EV (CRYO, WB/RAD)	7–8

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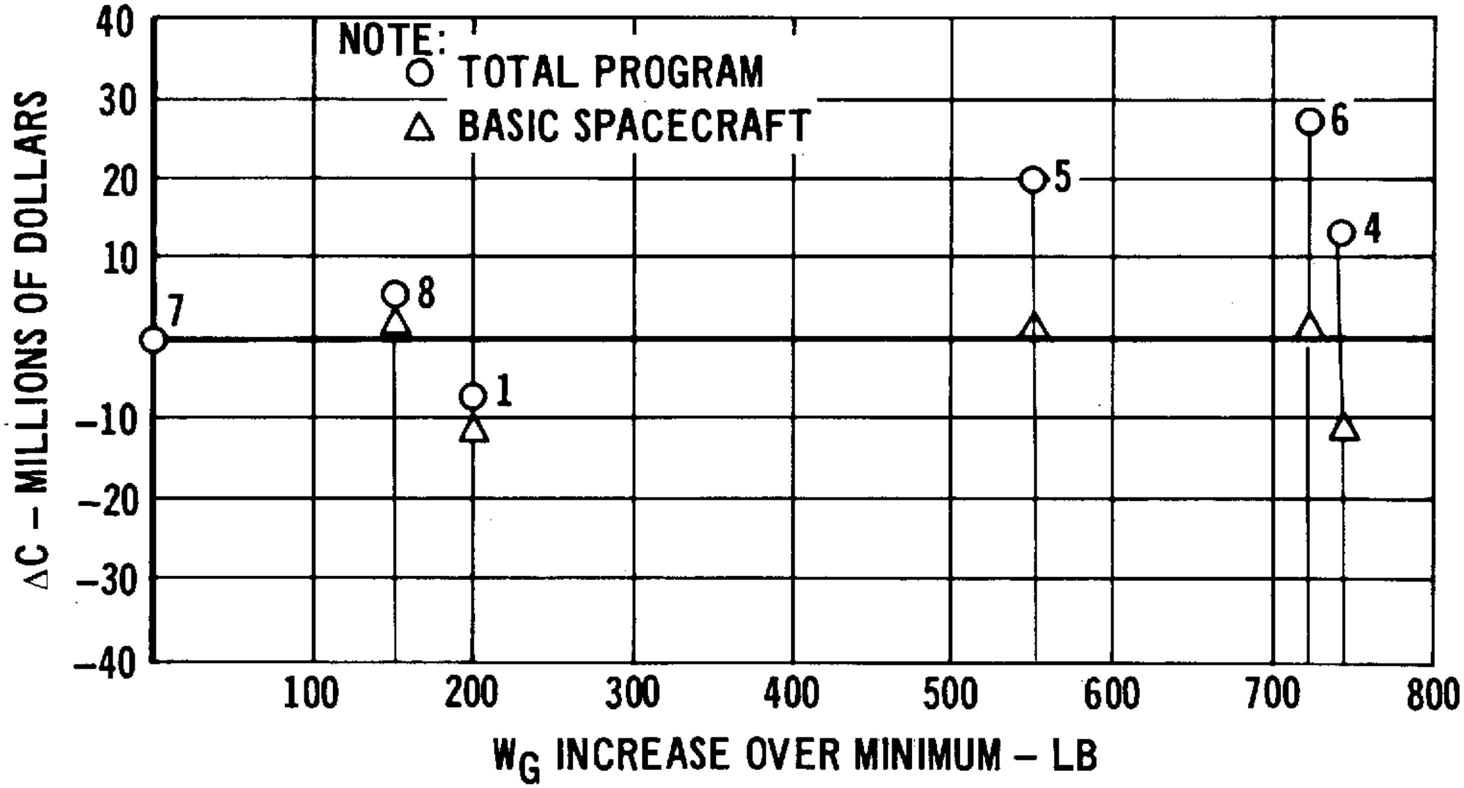
COST-WEIGHT TRENDS OF ENVIRONMENTAL CONTROL SYSTEM ALTERNATES

(IIB Spacecraft)

As with some other subsystems, least weight is not necessarily least cost. Gas storage of oxygen is cheaper although slightly heavier than cryogenic storage. There is only negligible difference in the spacecraft cost to include a radiator and the savings in total gross weight results in a definite cost advantage.

COST-WEIGHT TRENDS OF ENVIRONMENTAL CONTROL SYSTEMS ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)



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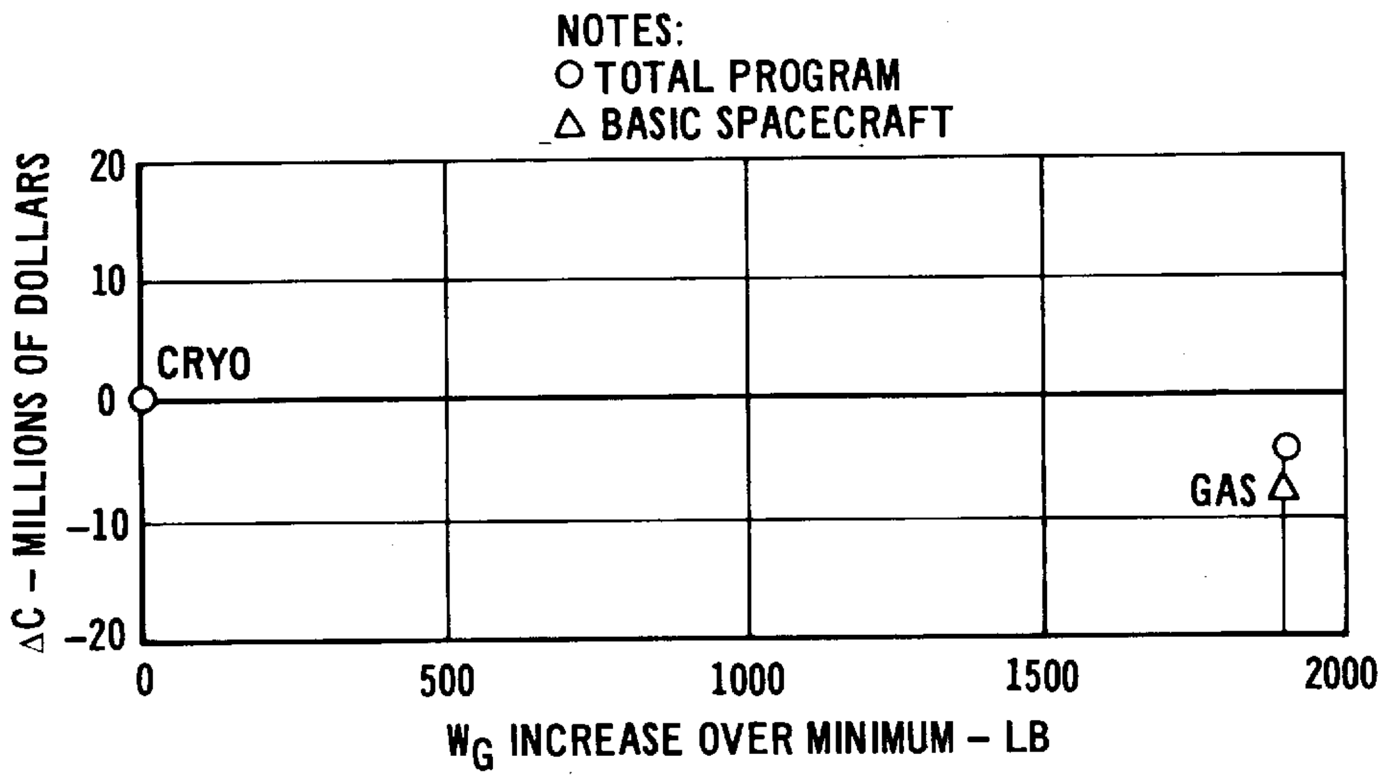
COST-WEIGHT TRENDS OF ENVIRONMENTAL CONTROL SYSTEM ALTERNATES

(IIE Spacecraft)

The only alternate available is the selection of oxygen storage since there is no mission module. As with the modular vehicle, the gas storage shows an advantage over the cryogenic storage.

COST-WEIGHT TRENDS OF ENVIRONMENTAL CONTROL SYSTEMS ALTERNATES

(IIE SPACECRAFT – U.S. LIFTING)



NOTE: BOTH CONCEPTS HAVE A WATER BOILER AND LiOH

OCPDM–244

ELECTRICAL POWER ALTERNATES

(IIB and IIE Spacecraft)

The dry weight and gross weight data are shown for the electrical power alternates of the lifting body spacecraft. The baseline approaches are 2 and 3 for the modular and upper stage spacecraft concepts respectively. These data are for the optimum cargo size for each spacecraft concept.

ELECTRICAL POWER ALTERNATES

SPACECRAFT CONCEPT	ELECTRICAL POWER CONCEPT	W_{DRY} (LB)	W_G (LB)	POWER SUPPLY	LOCATION
IIB MOD. LIFTING	2	21,935	70,628	FUEL CELLS & BATTERIES	F.C. IN EV RSS IN MM
	4	24,165	73,430	BATTERIES	EV
IIE U.S. LIFTING	3	379,490	1,624,073	FUEL CELLS & BATTERIES	EV
	4	383,112	1,636,354	BATTERIES	EV

OCPDM-238

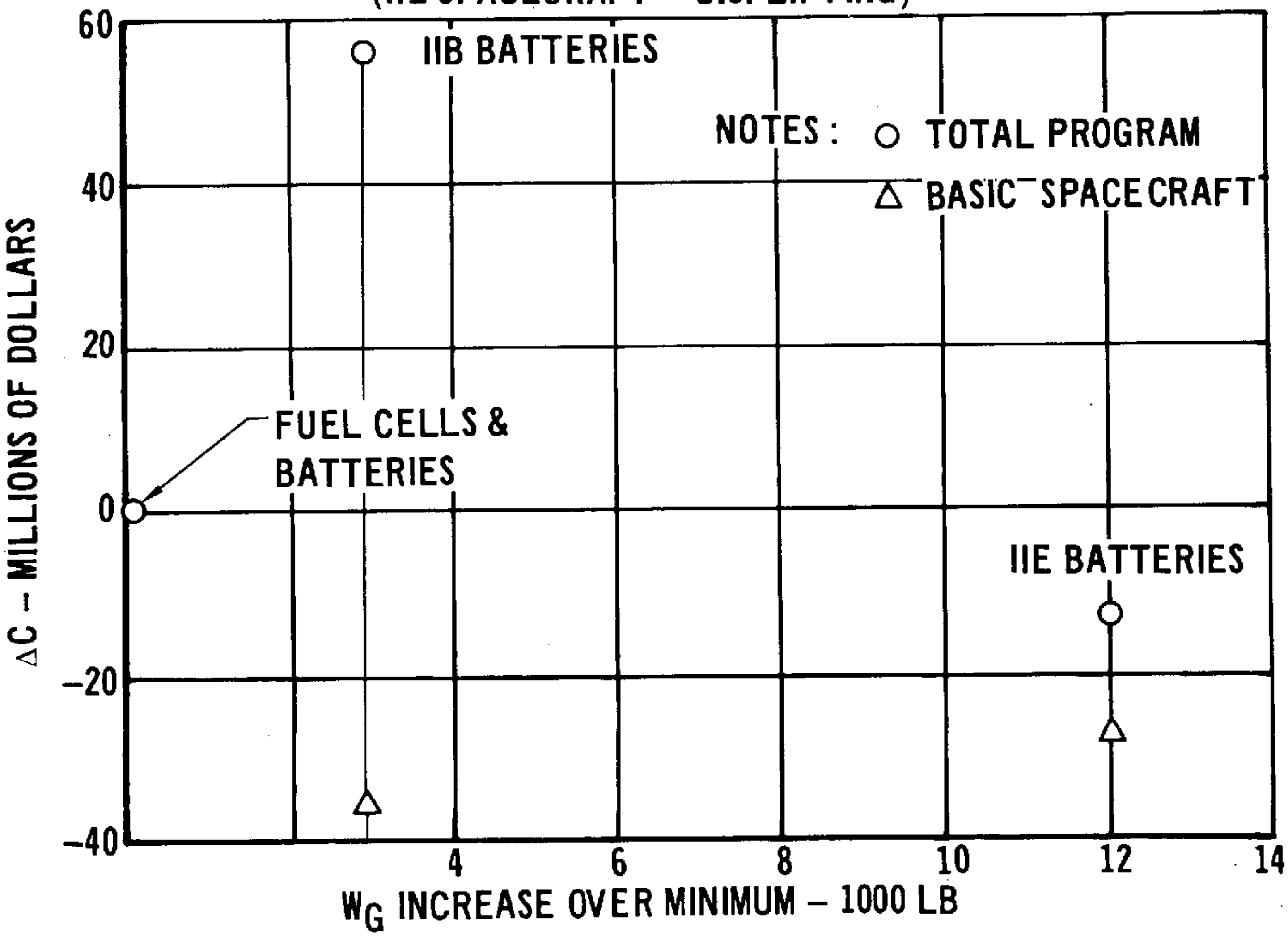
COST-WEIGHT TRENDS OF ELECTRICAL POWER ALTERNATES

(IIB and IIE Spacecraft)

The least weight approach for either spacecraft is to use fuel cells for the primary power and batteries for entry. Use of all batteries for the modular concept results in a decrease in spacecraft costs as would be expected but an increase in total program cost because of the weight penalty and increased launch vehicle costs. For the reusable upper stage the all battery approach results in a net saving of about 10 million dollars, although the total weight increase amounts to about 12,000 lbs. What is happening is that for the modular vehicle the weight increase amounts to about a 4% increase in thrown weight whereas for the upper stage it is only about 0.75%. Similar trends result for the ballistic vehicles.

COST-WEIGHT TRENDS OF ELECTRICAL POWER ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)
(IIE SPACECRAFT – U.S. LIFTING)



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HYDRAULIC POWER ALTERNATES
(IIB Spacecraft)

The dry weight and gross weight data are shown for the power supply alternates to actuate the aerodynamic surfaces on the modular lifting body spacecraft. All batteries were not considered a feasible alternate for the larger vehicles (C, D, E) because of the very high power load, and therefore were not investigated.

HYDRAULIC POWER ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)

CONCEPT	W_{DRY} (LB)	W_G (LB)	POWER TYPE
1	24,511	74,060	BATTERIES
2	21,935	70,628	TURBINE

OCPDM–240

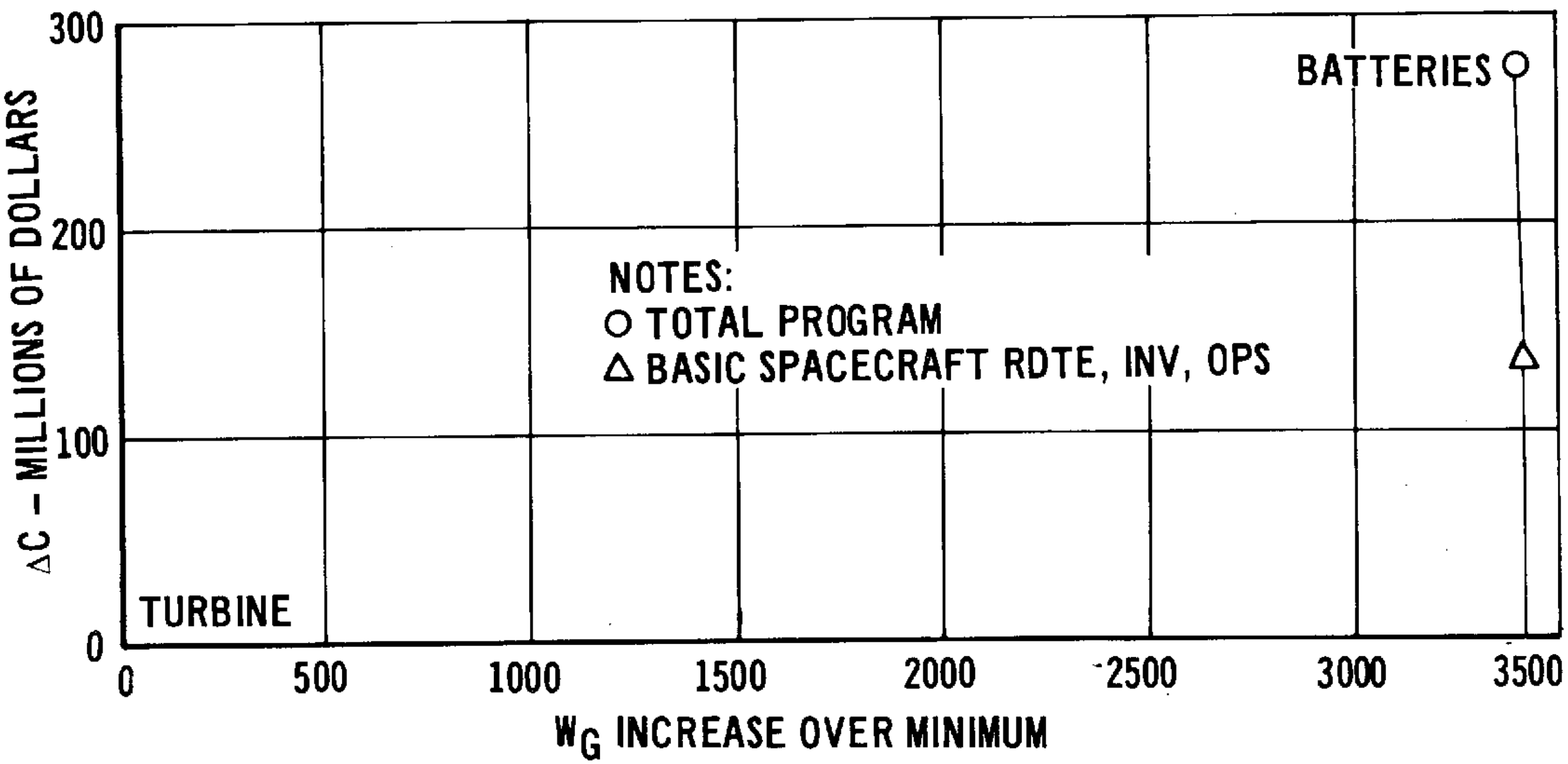
COST-WEIGHT TRENDS OF HYDRAULIC POWER ALTERNATES

(IIB Spacecraft)

The turbine gives the least cost and least weight approach to providing power for the hydraulic system. Using batteries increases the vehicle size enough to more than offset the savings even in the basic spacecraft development cost.

COST-WEIGHT TRENDS OF HYDRAULIC POWER ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)



OCPDM-241

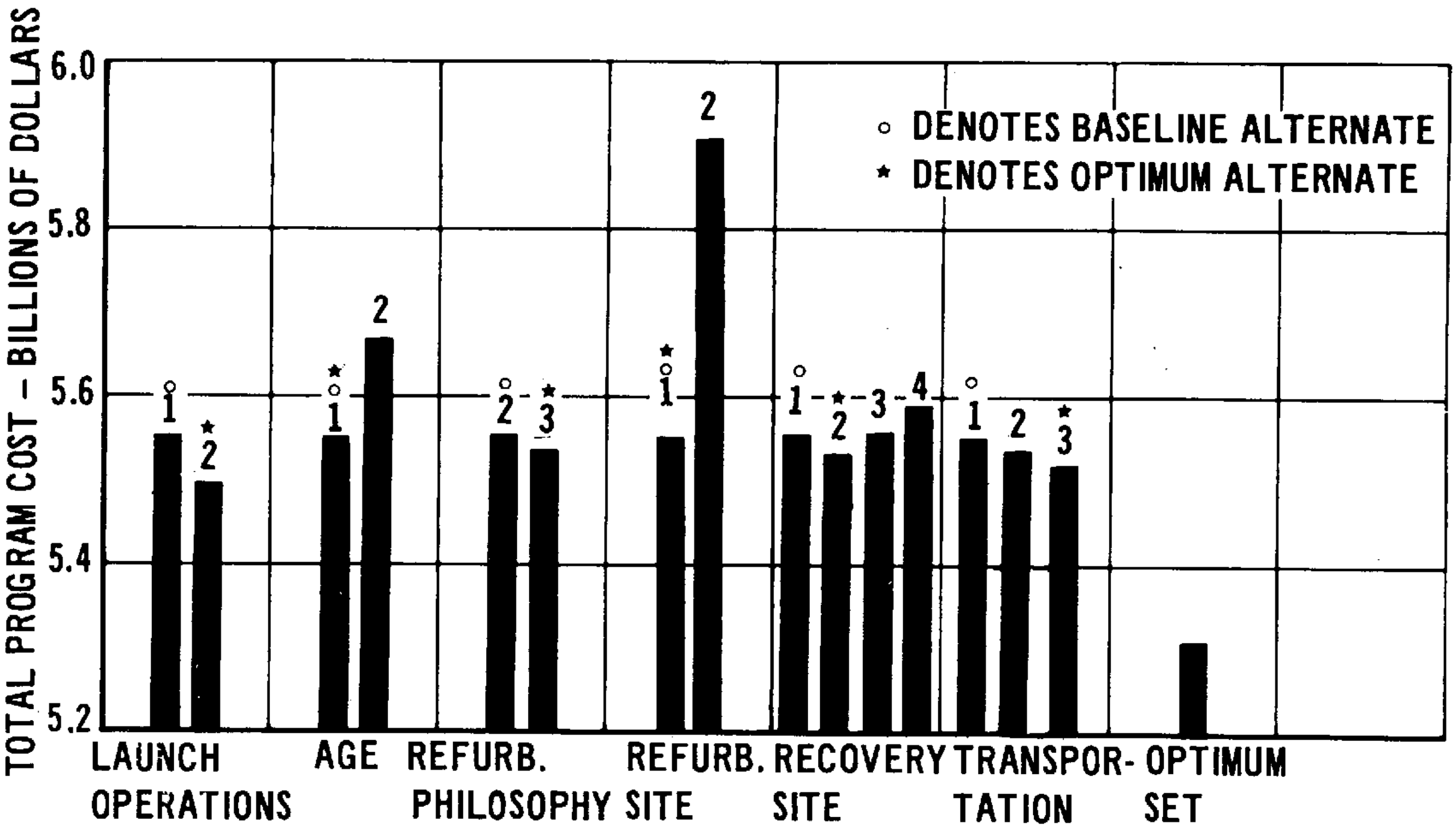
COMPARISON OF OPERATIONAL ALTERNATES

(Concept IIB)

Total program costs can be reduced by using integrated checkout (launch operations 2) because of the reduction in labor costs in both the launch operations and launch area support. The use of onboard checkout (AGE 2) reduces checkout time and therefore turnaround time, but not enough to offset the added cost for OBCO, the spacecraft weight and increased booster cost. The limited maintenance refurbishment philosophy (3) reduces both labor costs and recertification flow time. Both refurbishment alternates, limited maintenance and scheduled maintenance with testing (Refurb. 2) assume that all ablative panels are replaced during each recertification and that all radiative exterior panels are inspected and 20% are replaced during each recertification. With the baseline program total cargo used for this optimization, only the savings in labor costs was realized. The total calendar time for first unit recertification was reduced to 62% but because of the small program, this was not enough to reduce the number of vehicles in the inventory. The use of a new refurbishment site (Refurb. site = 2) shows the cost of adding a new site and the additional AGE at this site. Increasing the number of landing sites over two does not decrease spacecraft size or weight, and only two sites are required within the United States with a 24 hour return time. Therefore, increasing the number of sites only increases the cost of site activation, modification, and labor. Transportation by land (Transportation = 2) is slightly less expensive than by water and slightly more than by air but the difference is so slight that total program cost would not be used as a factor in the final choice of transportation mode.

COMPARISON OF OPERATIONAL ALTERNATES

(IIB SPACECRAFT – MOD. LIFTING)



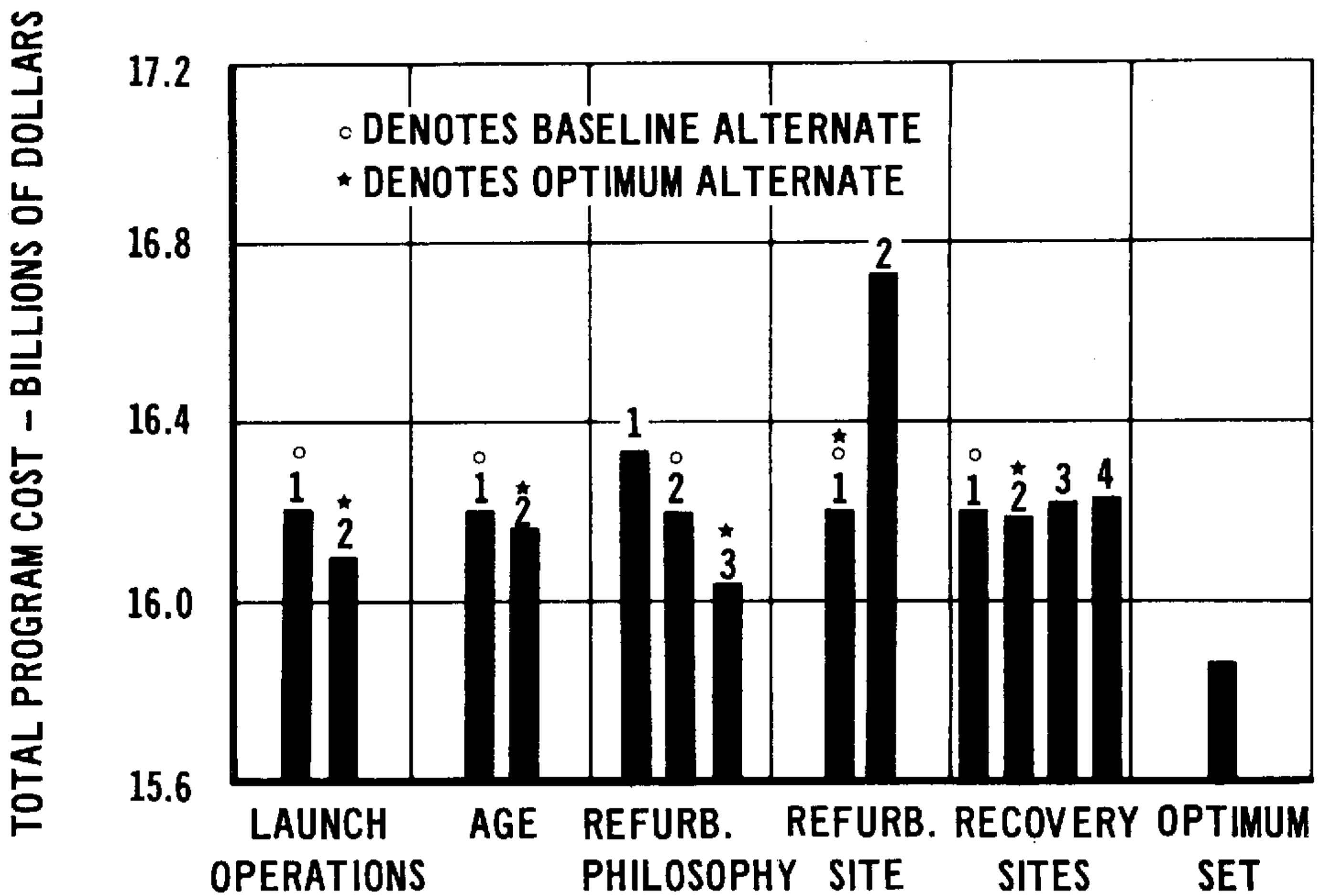
OCPDM-222

COMPARISON OF OPERATIONAL ALTERNATES - IIE
(CONCEPT II E)

The large reusable upper stage exhibits the same general trends as the modular spacecraft with the exception that the use of on-board checkout reduces the calendar time required for recertification enough that one less vehicle is required. No transportation alternates were defined; water transportation was considered the only feasible approach because of the spacecraft size.

COMPARISON OF OPERATIONAL ALTERNATES

(IIE SPACECRAFT – U.S. LIFTING)



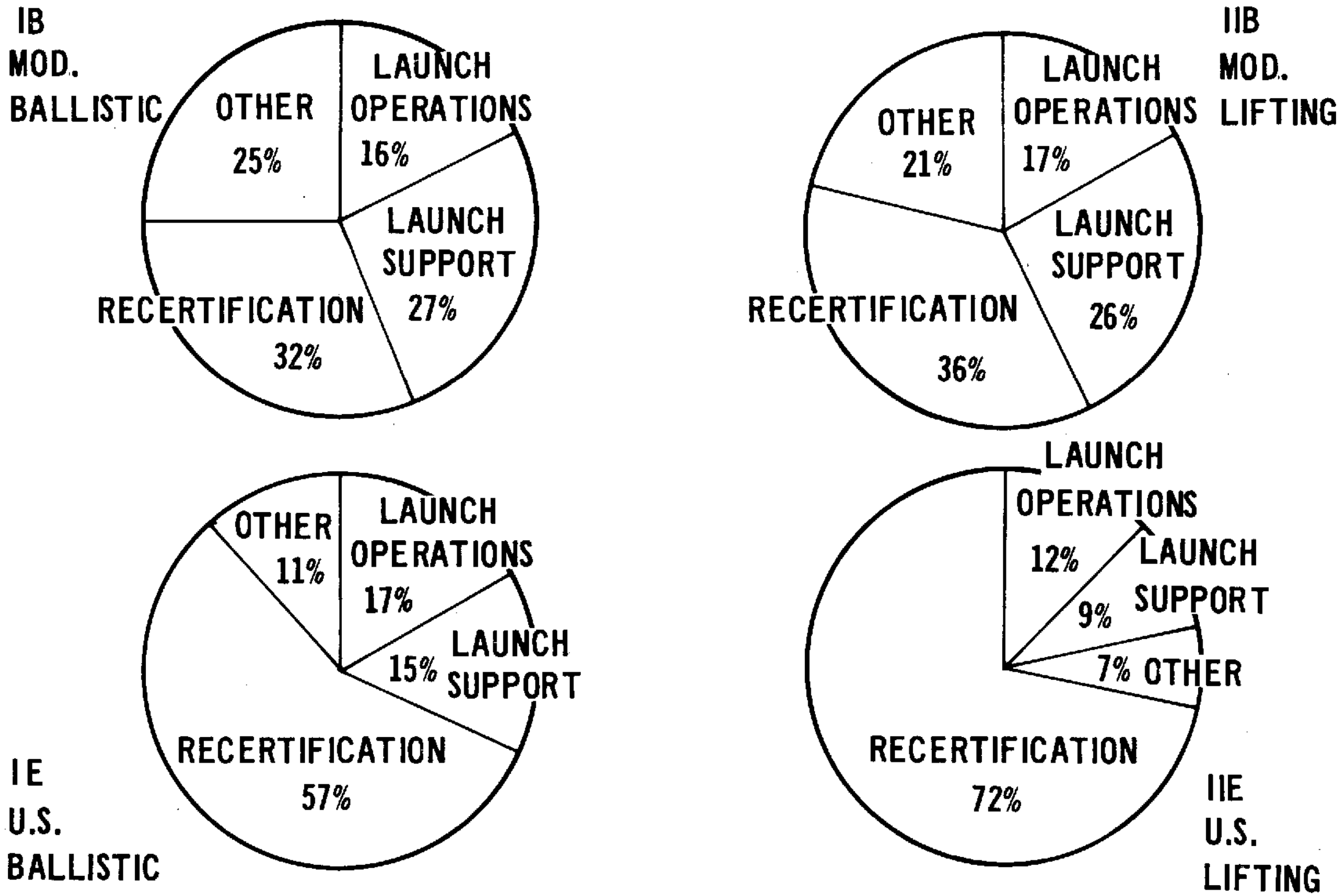
OCPDM-223

SPACECRAFT OPERATIONAL COST BREAKDOWN

The operational costs are composed of three major cost categories and several smaller categories which have been lumped together. These smaller ones are AGE and facility maintenance, mission support, integration and technical support, recovery, and transportation. Launch operations are those activities directly connected with the launching of a spacecraft. Launch support is the cost of supporting the direct activities.

Recertification is the largest cost category and is composed of labor and material costs as discussed in other charts of this presentation. Average launch operations costs for the modular vehicles ranged from $885,000 to $980,000, and for the large integral vehicles ranged from $2.78 millions to $3.56 millions. These costs reflect the conservative launch operations philosophy of the present manned spaceflight programs.

SPACECRAFT OPERATIONAL COST BREAKDOWN

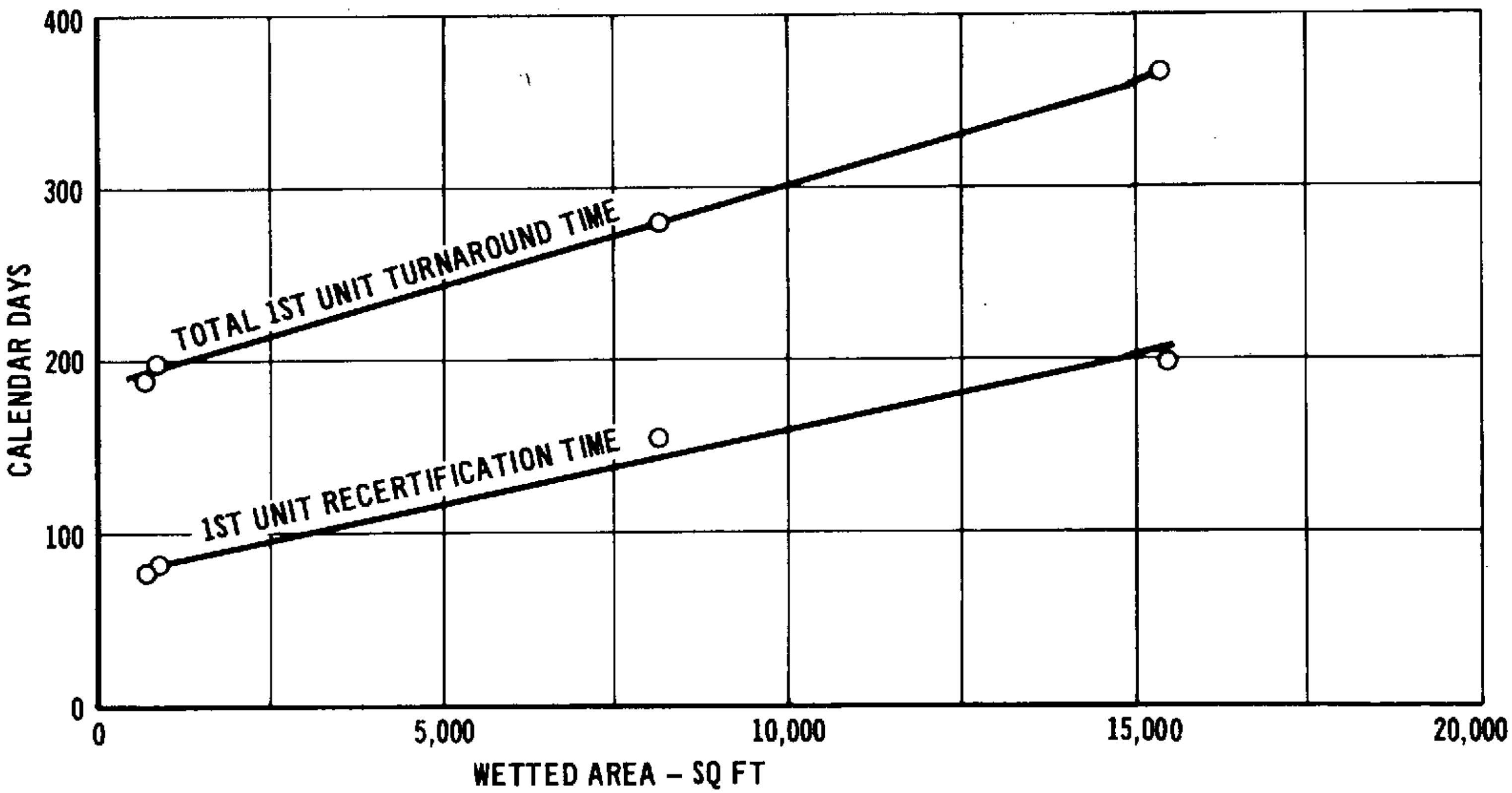


OCPDM-268

TURNAROUND TIME VS WETTED AREA

As the size of the vehicle increases, the turnaround time increases. The parameter which best reflects this is wetted area. There appears to be a nearly linear relationship between turnaround time and wetted area as shown on this chart.

TURNAROUND TIME VS WETTED AREA



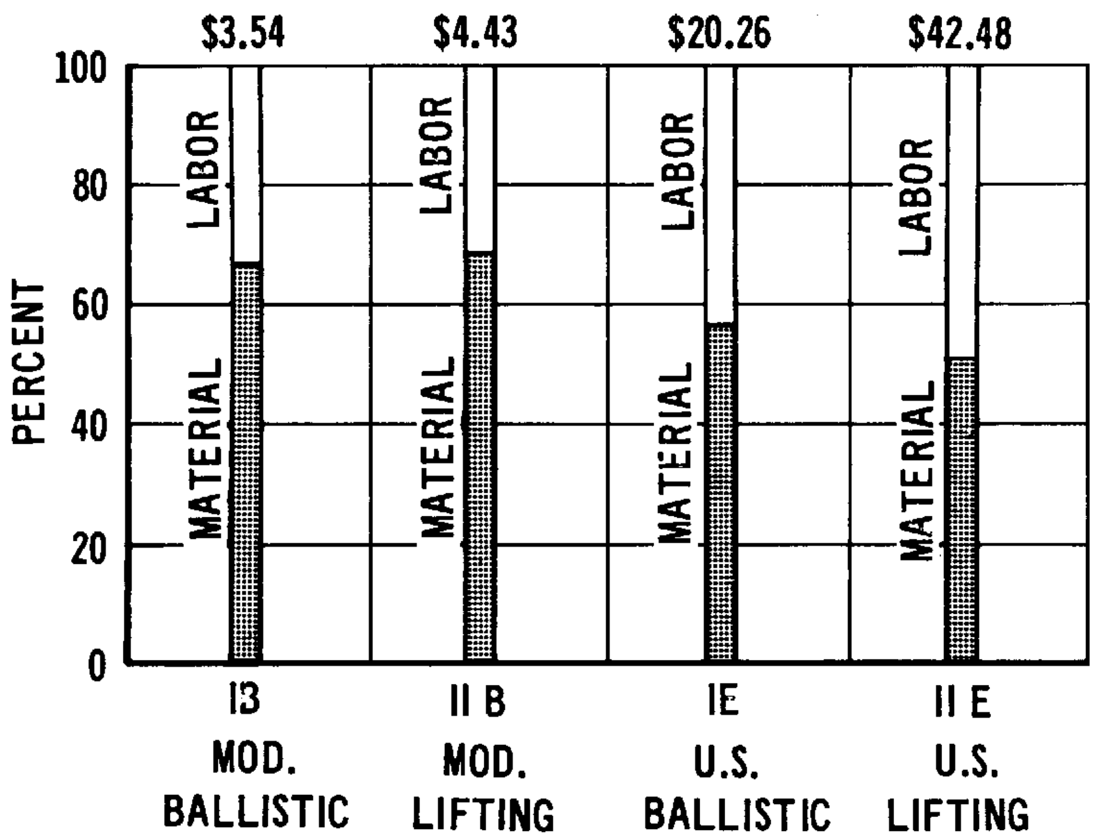
OCPDM-269

RECERTIFICATION COST BREAKDOWN

At the top of the columns on this chart is the estimated first unit cost for recertification. This is then divided between labor and material costs. As shown, the material costs are the major portion due to the assumed replacement schedule and the long program life.

Labor costs are divided between thermo-structural reconditioning, subsystem scheduled replacement, and testing. The first is influenced by the size of the vehicle because it is a function of the wetted surface area which must be inspected and serviced. Testing is assumed to be similar to that done during production as the final systems test prior to delivery, but without a firing test of any of the propulsion subsystems.

RECERTIFICATION COST BREAKDOWN

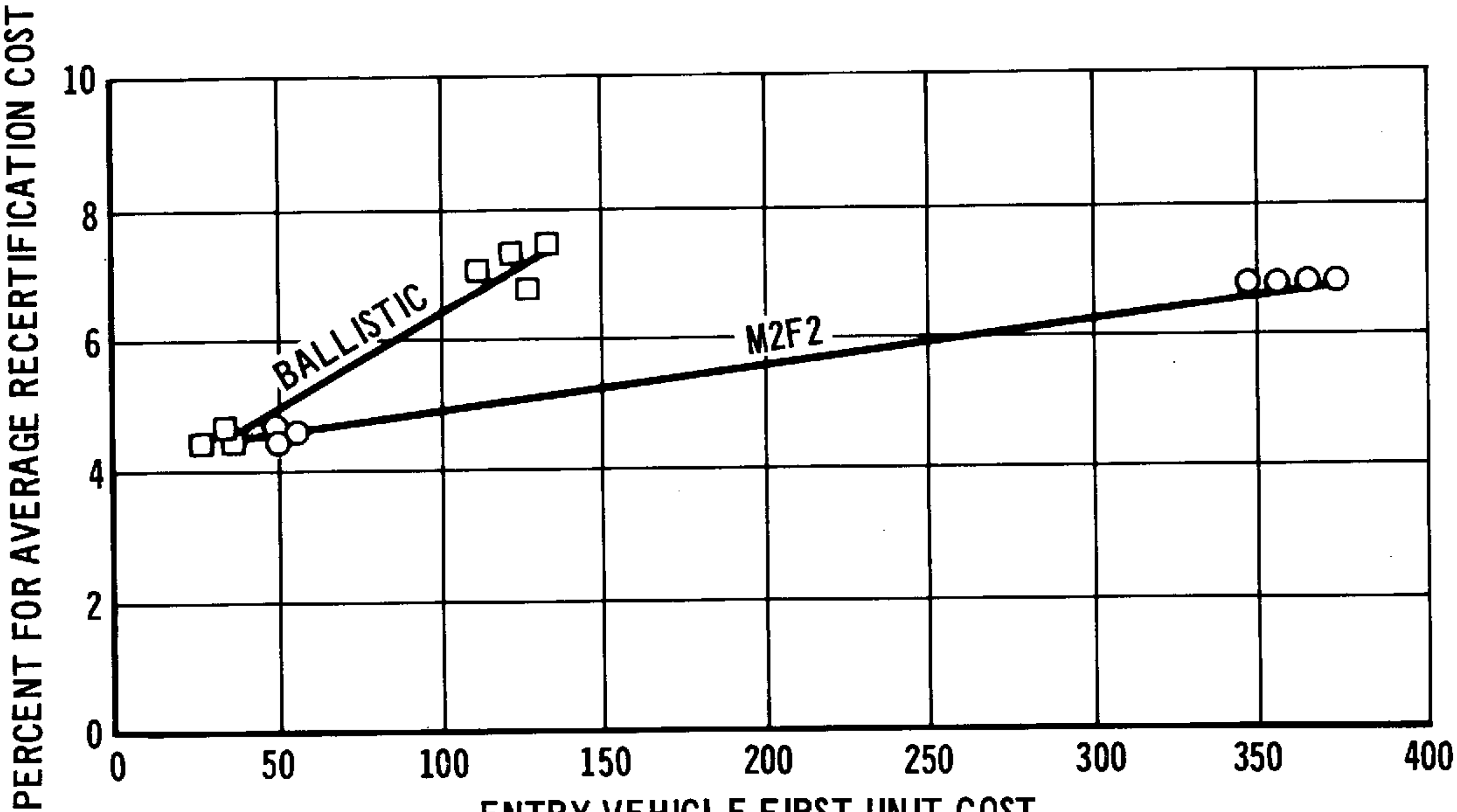


OCPDM-267

RECERTIFICATION AS PERCENT OF 1ST UNIT HARDWARE

Recertification costs are often discussed in terms of percentages of first unit hardware costs. This chart presents the average recertification costs as a percentage of the first unit entry vehicle costs. Average recertification costs for a typical ten-year program using the modular vehicles will have a cost of about 4.5% of first unit costs. A similar program using the integral vehicles will have a cost between 6.5% and 7.5% of first unit costs.

RECERTIFICATION AS PERCENT OF 1ST UNIT HARDWARE



OCPDM-265

IB RECURRING PLUS INVESTMENT COST VARIATION WITH PAYLOAD SIZE

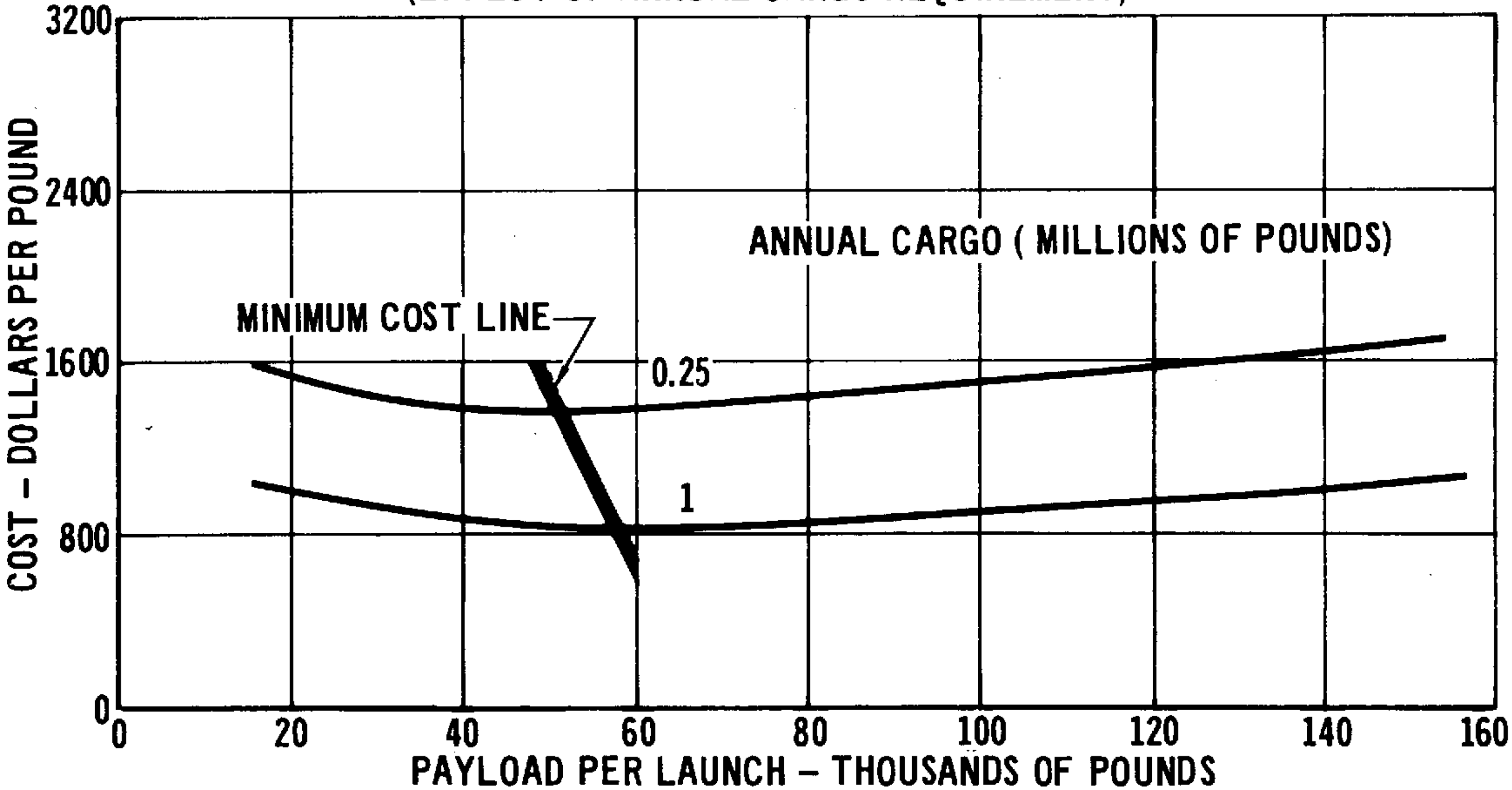
(Effect of Annual Cargo Requirement)

These costs exhibit an optimum size which increases slightly with program size. The cost in $/lb decreases for the modular ballistic spacecraft concept by about 40% as the program size goes up by a factor of 4.

The primary reason for the high recurring costs is the expendable launch vehicle.

RECURRING PLUS INVESTMENT COST VARIATION

(IB SPACECRAFT – MOD. BALLISTIC)
(EFFECT OF ANNUAL CARGO REQUIREMENT)



OCPDM–249

IIB RECURRING PLUS INVESTMENT COST VARIATION WITH PAYLOAD SIZE

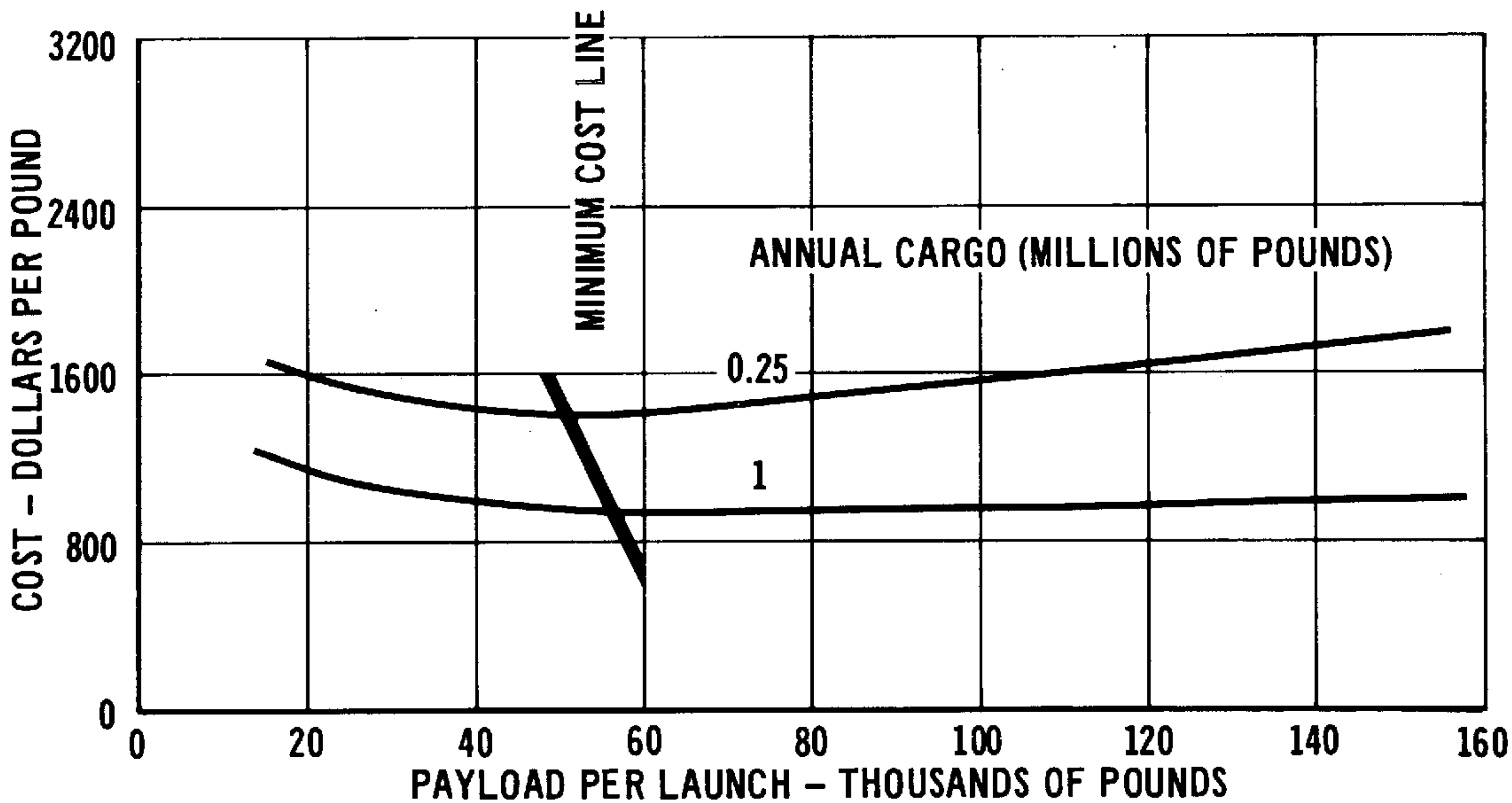
(Effect of Annual Cargo Requirement)

The minimum $/lb occurs for about the same size payloads for the modular lifting body as for the modular ballistic. Again the reason for the high cost is the expendable launch vehicle. The lifting body has slightly higher costs for a given payload than the ballistic because the spacecraft is more expensive, slightly heavier, and requires a larger launch vehicle thrown weight.

RECURRING PLUS INVESTMENT COST VARIATION

(IIB SPACECRAFT – MOD. LIFTING)

(EFFECT OF ANNUAL CARGO REQUIREMENT)



OCPDM–250

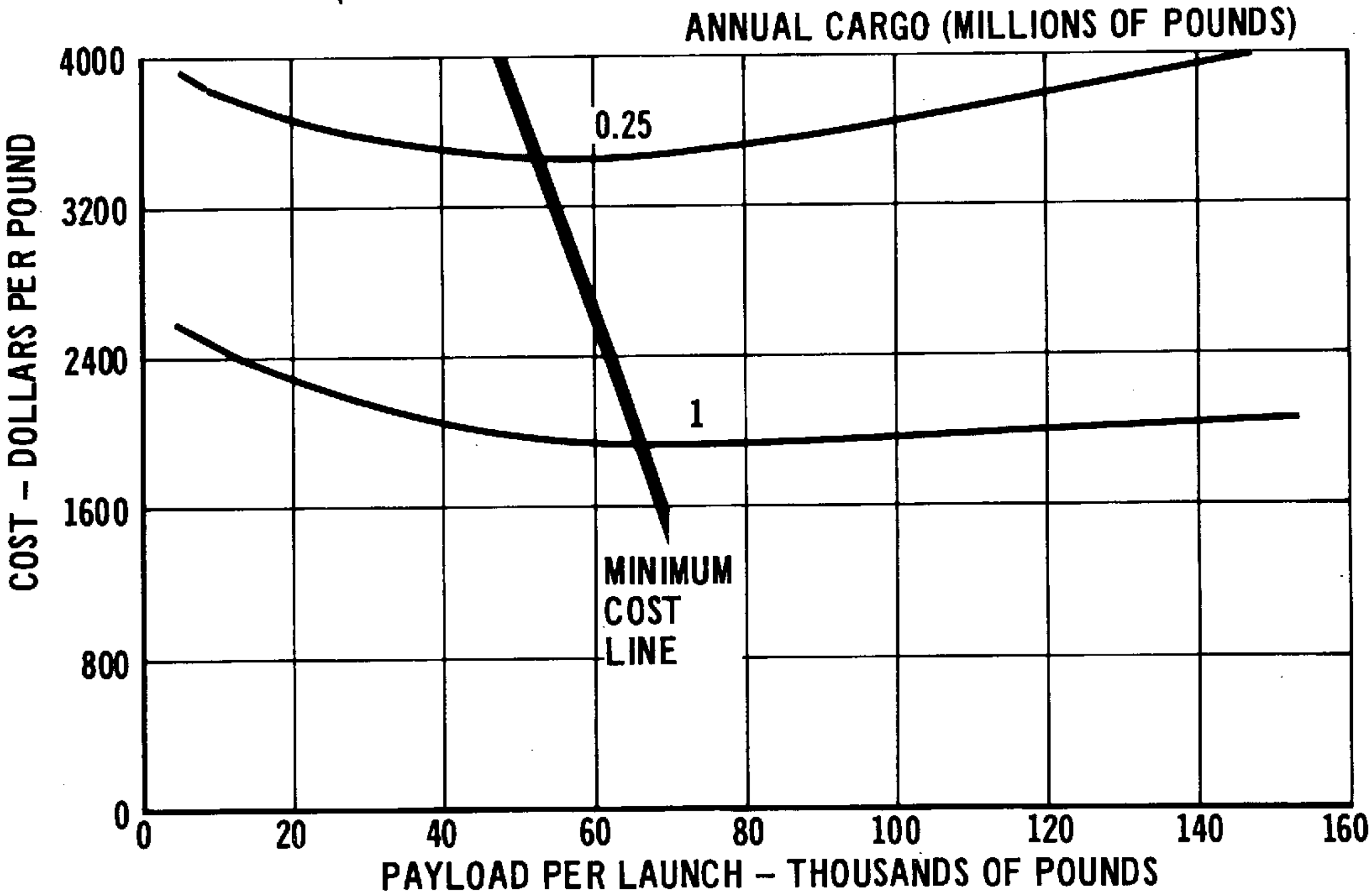
IIE RECURRING PLUS INVESTMENT COST VARIATION WITH PAYLOAD SIZE

(Effect of Annual Cargo Requirement)

The spacecraft investment and operations costs increase because the size of the vehicle has increased. The wetted area of a reusable upper stage lifting is about 16 times that of a modular vehicle. Several operations cost items are related to size and therefore significantly increase. However, the largest contributor to this cost is still the expendable launch vehicle and launch vehicle operation.

IIE RECURRING PLUS INVESTMENT COST VARIATION

(IIE SPACECRAFT – U.S. LIFTING)
(EFFECT OF ANNUAL CARGO REQUIREMENT)



OCPDM-251

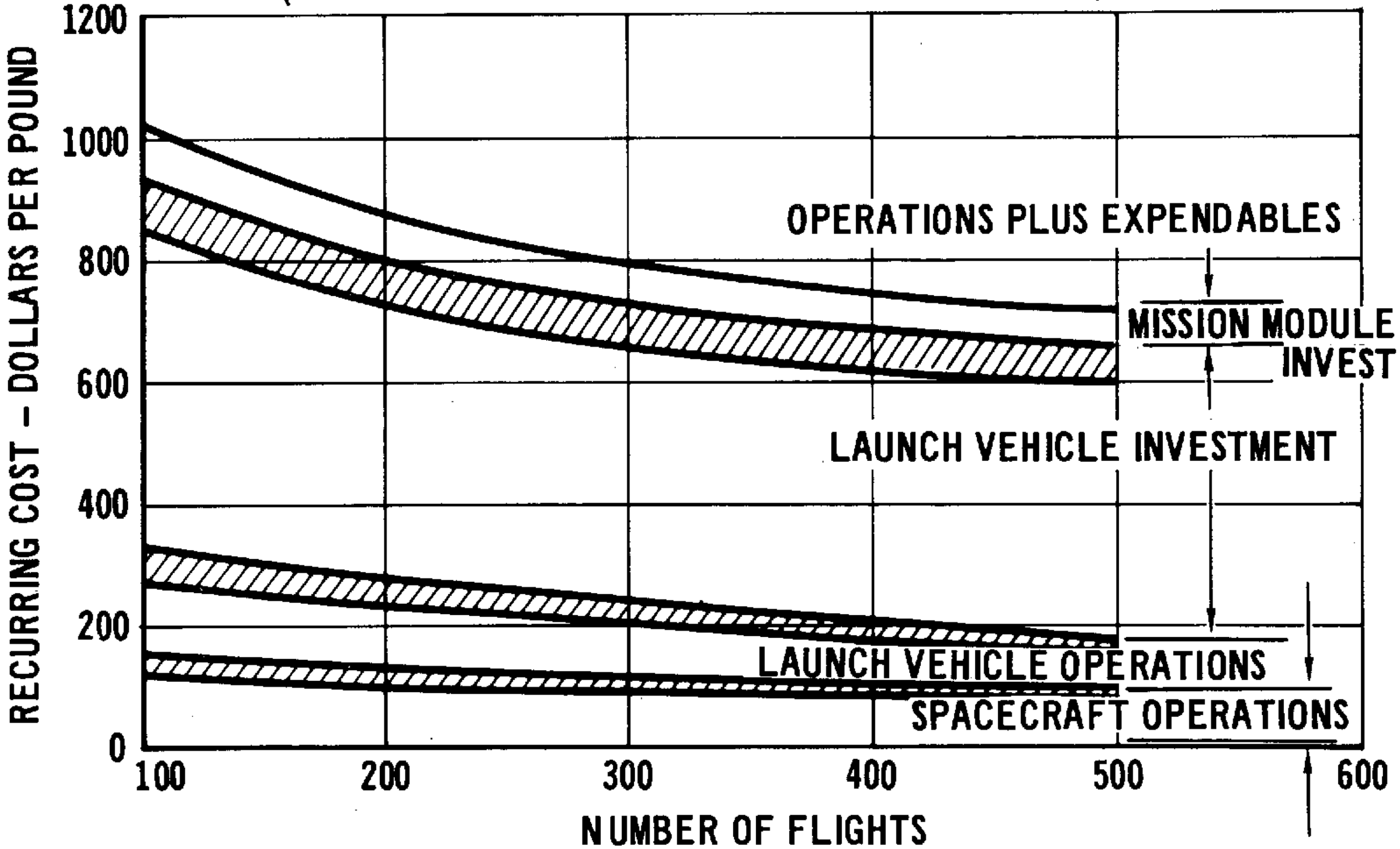
IIB RECURRING COST BREAKDOWN WITH NUMBER OF FLIGHTS

(Payload = 50,000 Pounds)

The variation of recurring cost with total number of flights is shown for a payload per launch of 50,000 lbs and broken down into several categories to provide some visibility. The costs decrease with increasing numbers of flights as would be expected but the slope of the curve is rapidly decreasing. For the modular lifting body vehicle the spacecraft related costs are less than $100/lb out of a total of $700/lb.

RECURRING COST BREAKDOWN WITH NUMBER OF FLIGHTS

(IIB SPACECRAFT – MOD. LIFTING)
(PAYLOAD = 50,000 POUNDS)
(SHADED AREA REPRESENTS FEE & MANAGEMENT)



OCPDM–255

IIE RECURRING COST BREAKDOWN WITH NUMBER OF FLIGHTS

(Payload = 50,000 Pounds)

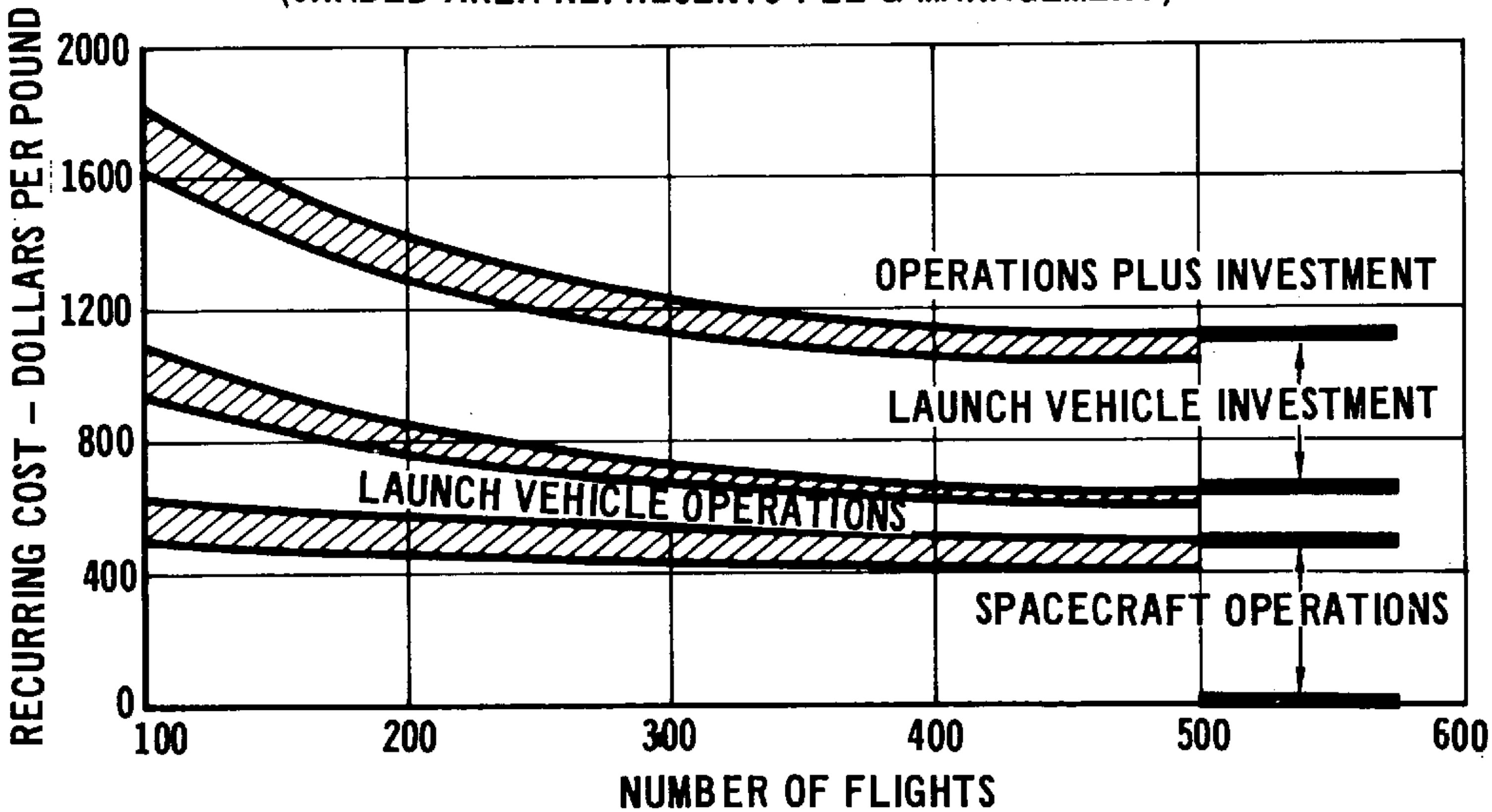
The same trends are exhibited for the reusable upper stage as for the modular vehicle except that the spacecraft operations represent about 40% of the total.

RECURRING COST BREAKDOWN WITH NUMBER OF FLIGHTS

(IIE SPACECRAFT – U.S. LIFTING)

PAYLOAD = 50,000 POUNDS

(SHADED AREA REPRESENTS FEE & MANAGEMENT)



OCPDM-256

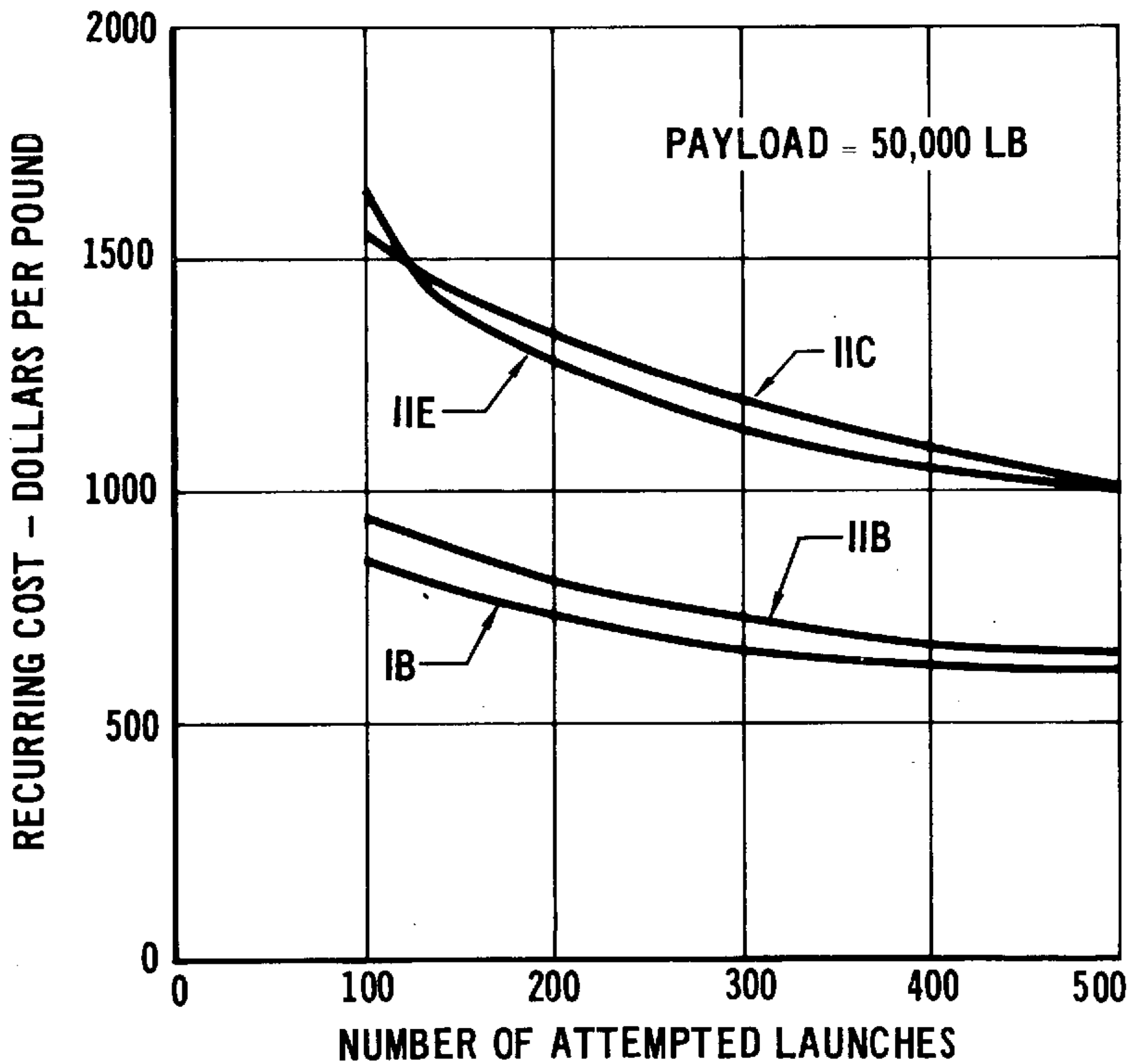
RECURRING COST VARIATION WITH CONFIGURATION

(Including Expendable Cost)
Payload = 50,000 Pounds

This chart summarizes the recurring cost variation for several concepts. The reason for the cross-over of the IIC and IIE concepts is because of different launch vehicle cost trends. The B and C spacecraft use a two stage expendable solid/liquid launch vehicle and the IIE spacecraft (reusable upper stage) use a 260 inch solid booster.

RECURRING COST VARIATION WITH CONFIGURATION

(INCLUDING EXPENDABLES)



OCPDM-258

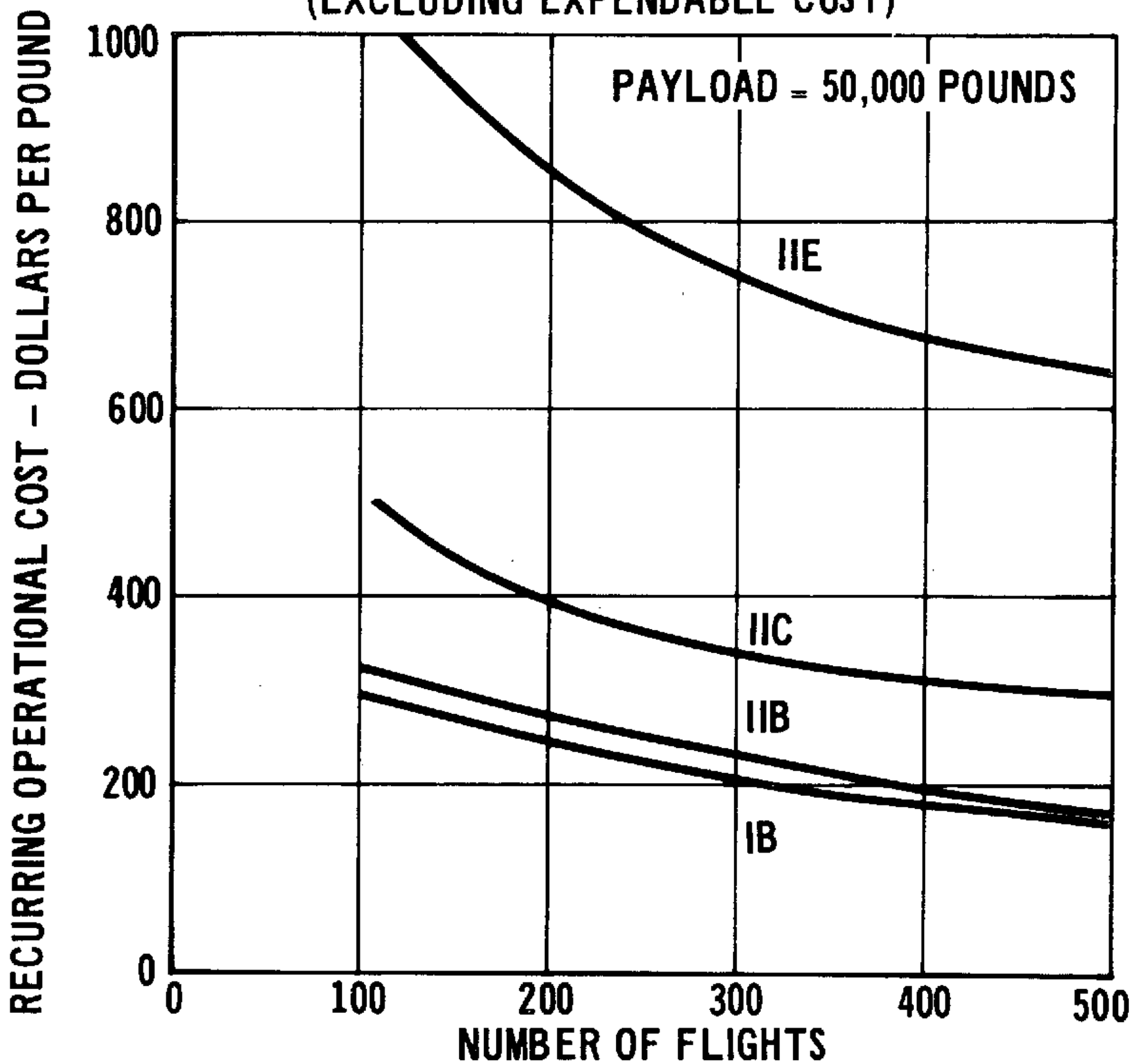
RECURRING OPERATIONAL COST VARIATION WITH CONFIGURATION

(Excluding Expendable Cost)

This summarizes the spacecraft and launch vehicle operation costs, excluding all expendable hardware. For the modular vehicles the costs are divided approximately half and half between the spacecraft and launch vehicle. For the IIE vehicle the costs are approximately 2/3 spacecraft.

RECURRING OPERATIONAL COST VARIATION WITH CONFIGURATION

(EXCLUDING EXPENDABLE COST)



OCPDM-257

IB RECURRING COST BREAKDOWN WITH PAYLOAD VARIATION
(Based on 100 Flights)

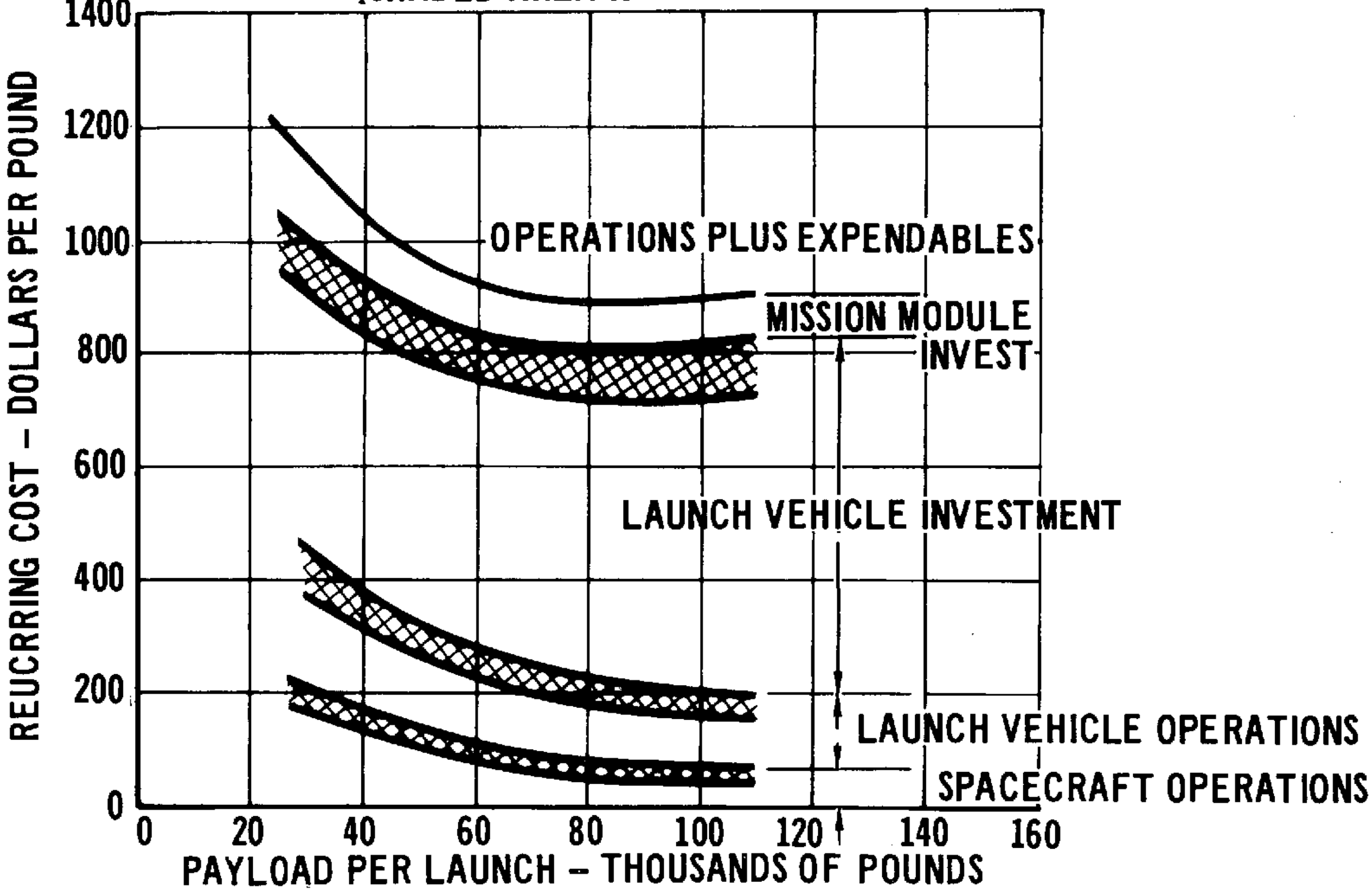
For a program consisting of 100 flights the payload size which results in the least recurring cost in $/lb is considerably larger than the size based on a given program requirement. It can be seen that for the modular ballistic spacecraft,the spacecraft and launch vehicles operation costs are decreasing with increasing size but the launch vehicle investment costs increase.

RECURRING COST BREAKDOWN WITH PAYLOAD VARIATION

(IB SPACECRAFT – MOD. BALLISTIC)

(BASED ON 100 FLIGHTS)

(SHADED AREA IS FEE & MANAGEMENT)



OCPDM–252

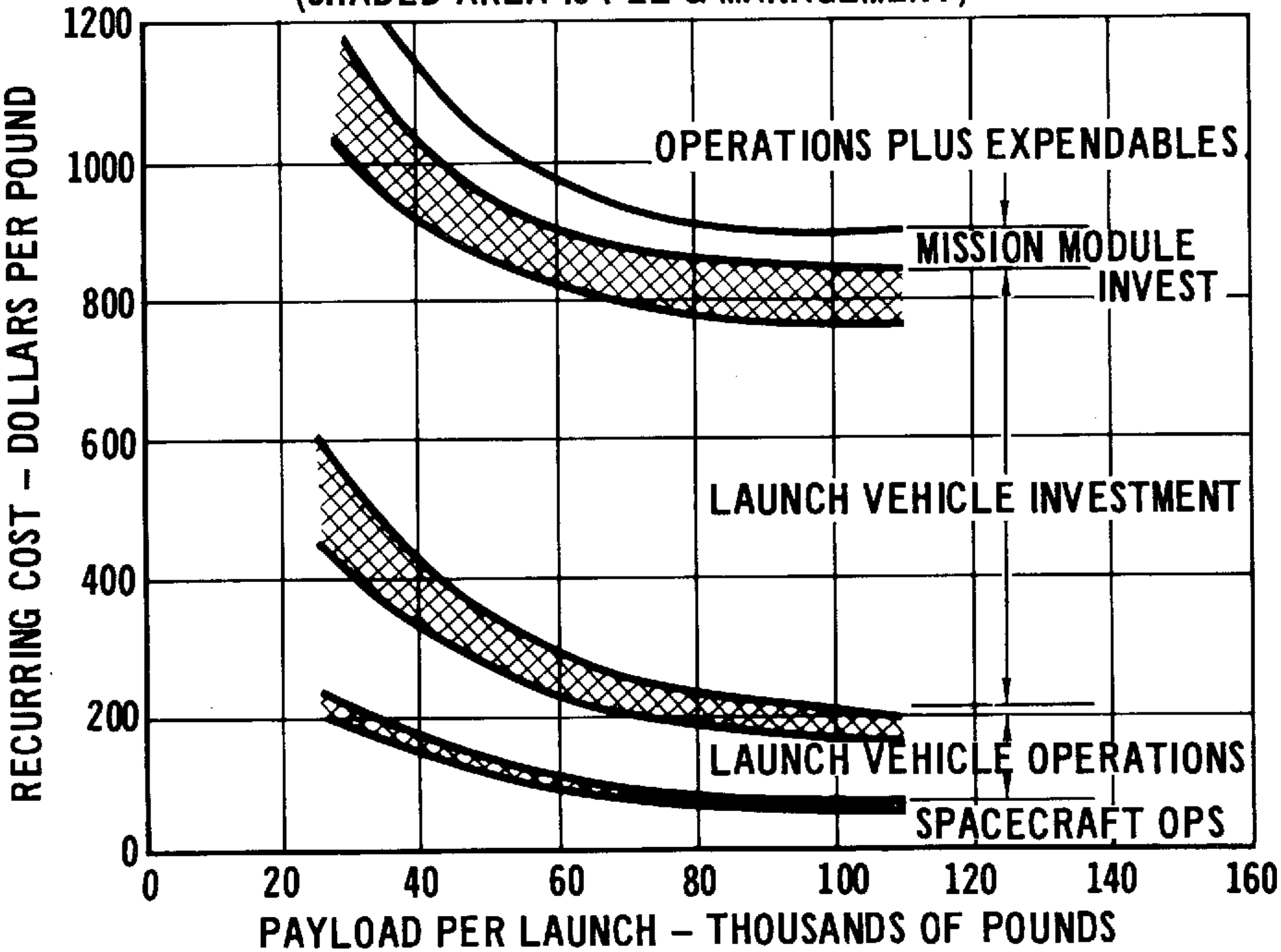
IIB RECURRING COST BREAKDOWN WITH PAYLOAD VARIATION

Based on 100 Flights

The trends for the modular lifting body are identical to those of the modular ballistic spacecraft. The optimum payload per launch is shifted out to a slightly higher value because of a slightly larger spacecraft size for a given payload.

RECURRING COST BREAKDOWN WITH PAYLOAD VARIATION

(IIB SPACECRAFT – MOD. LIFTING)
(BASED ON 100 FLIGHTS)
(SHADED AREA IS FEE & MANAGEMENT)



OCPDM-253

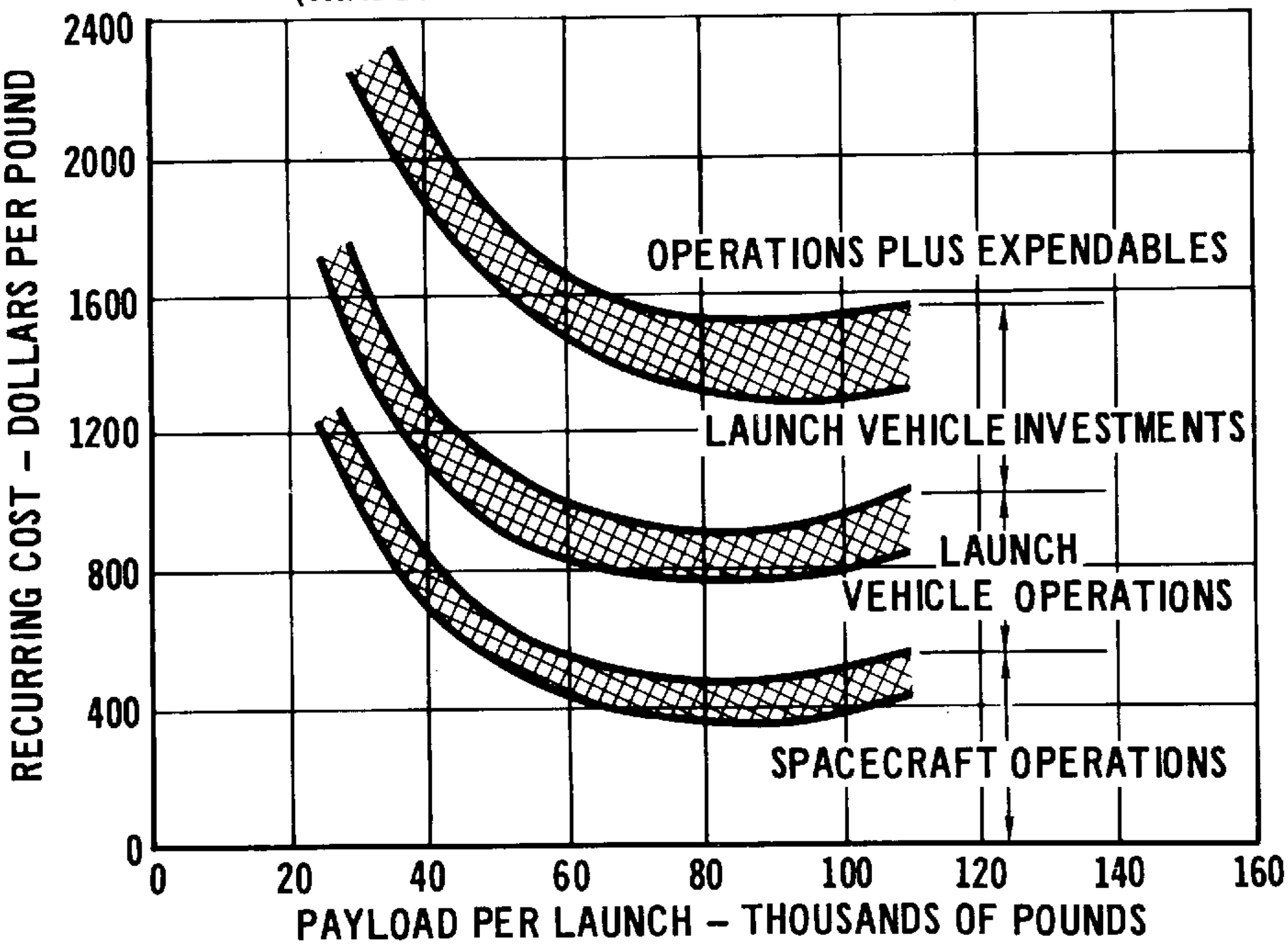
IIE RECURRING COST BREAKDOWN WITH PAYLOAD VARIATION

Based on 100 Flights

The reusable upper stage lifting body spacecraft uses an expendable 260 in solid first stage and shows again the shift toward larger payload sizes for a fixed program of 100 flights. The launch vehicle costs on a dollars per pound of payload basis are decreasing at the higher payloads because the increment of payload represents only a small increment in launch vehicle size and cost for the solid first stage.

RECURRING COST BREAKDOWN WITH PAYLOAD VARIATION

(IIE SPACECRAFT – U.S. LIFTING)
(BASED ON 100 FLIGHTS)
(SHADED AREA IS FEE & MANAGEMENT)



OCPDM–254

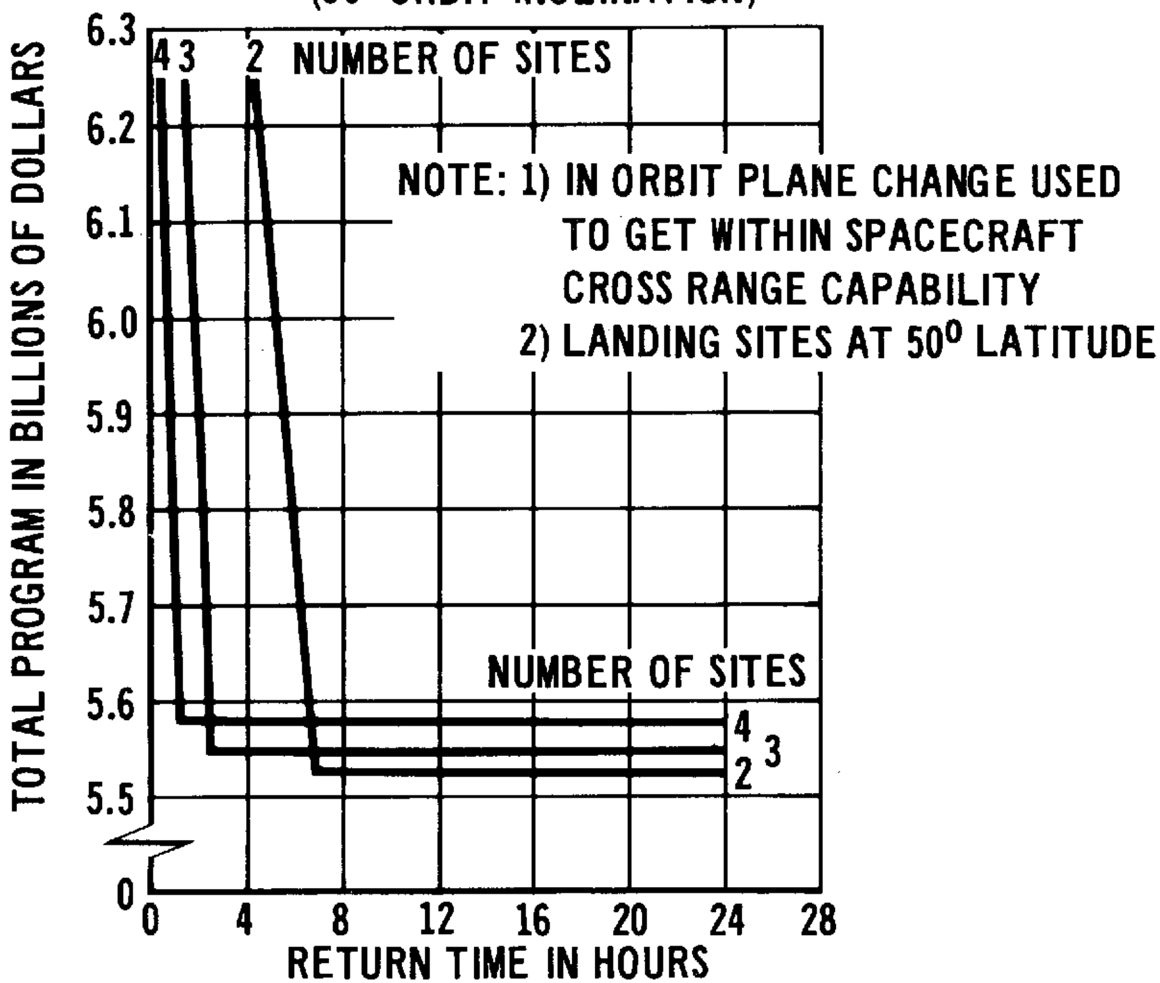
IIB COST VS. RETURN TIME AND NUMBER OF SITES
(50° Orbit Inclination)

The modular lifting body spacecraft is used to show the effect of the minimum time for return and the number of landing sites available. The landing sites are assumed to be evenly distributed longitudinally and at a latitude of 50°. The cross range capability of the lifting body is 600 n. mi. Two sites allows for return in seven hours from a 50° orbit inclination but shorter times require a phasing maneuver or additional sites. Four sites can provide a one hour return with no phasing maneuvers.

COST VS. RETURN TIME AND NUMBER OF SITES

(IIB SPACECRAFT – MOD. LIFTING)

(50^0 ORBIT INCLINATION)



OCPDM–259

IIB COST VS. RETURN TIME AND NUMBER OF SITES

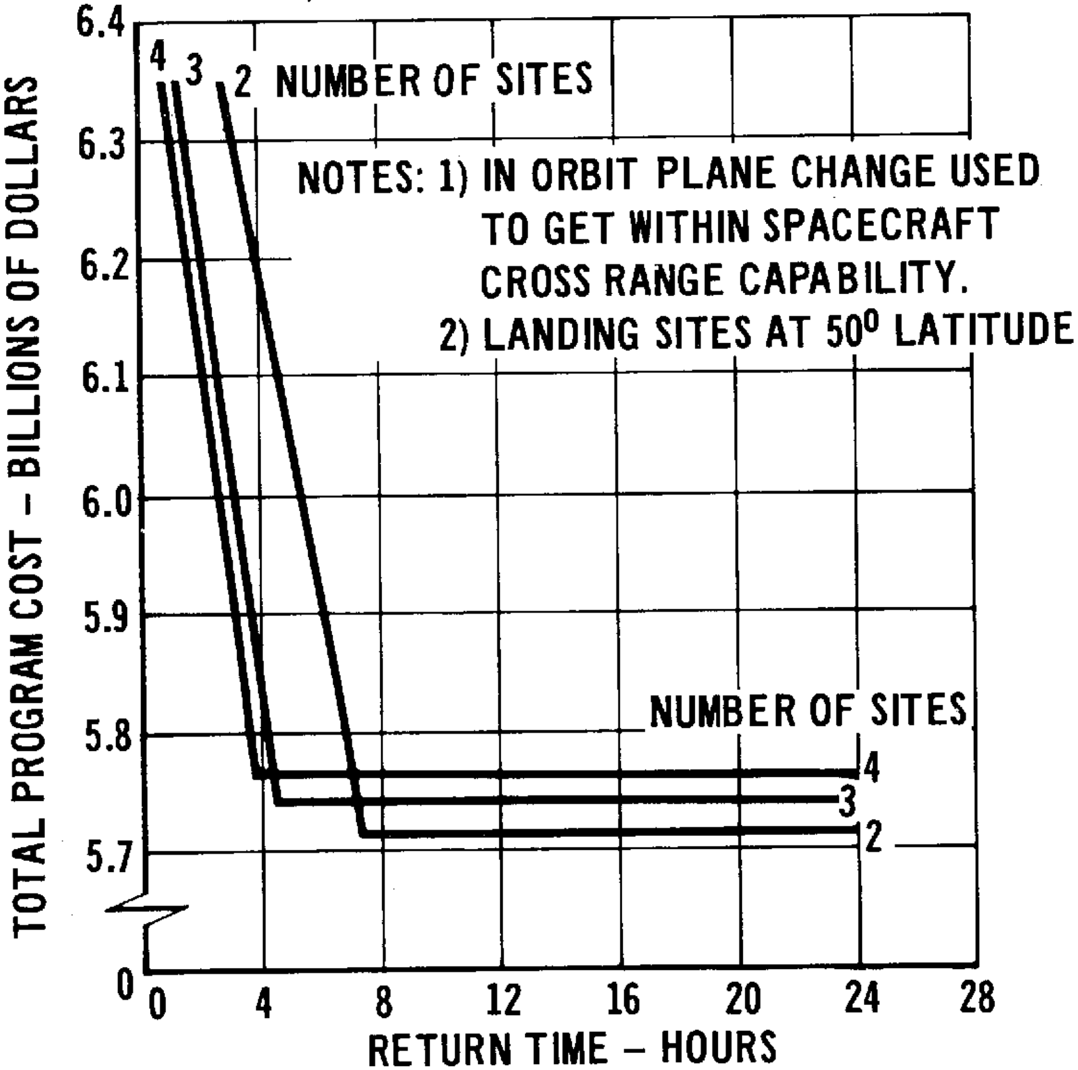
(70° Orbit Inclination)

The basic total program cost goes up slightly for the 70° orbit because the launch vehicle costs increase. However, the other trends are the same as for the 50° orbit except that four sites now only provides a four hour return capability without phasing.

COST VS. RETURN TIME AND NUMBER OF SITES

(IIB SPACECRAFT – MOD. LIFTING)

(70^0 ORBIT INCLINATION)



OCPDM–260

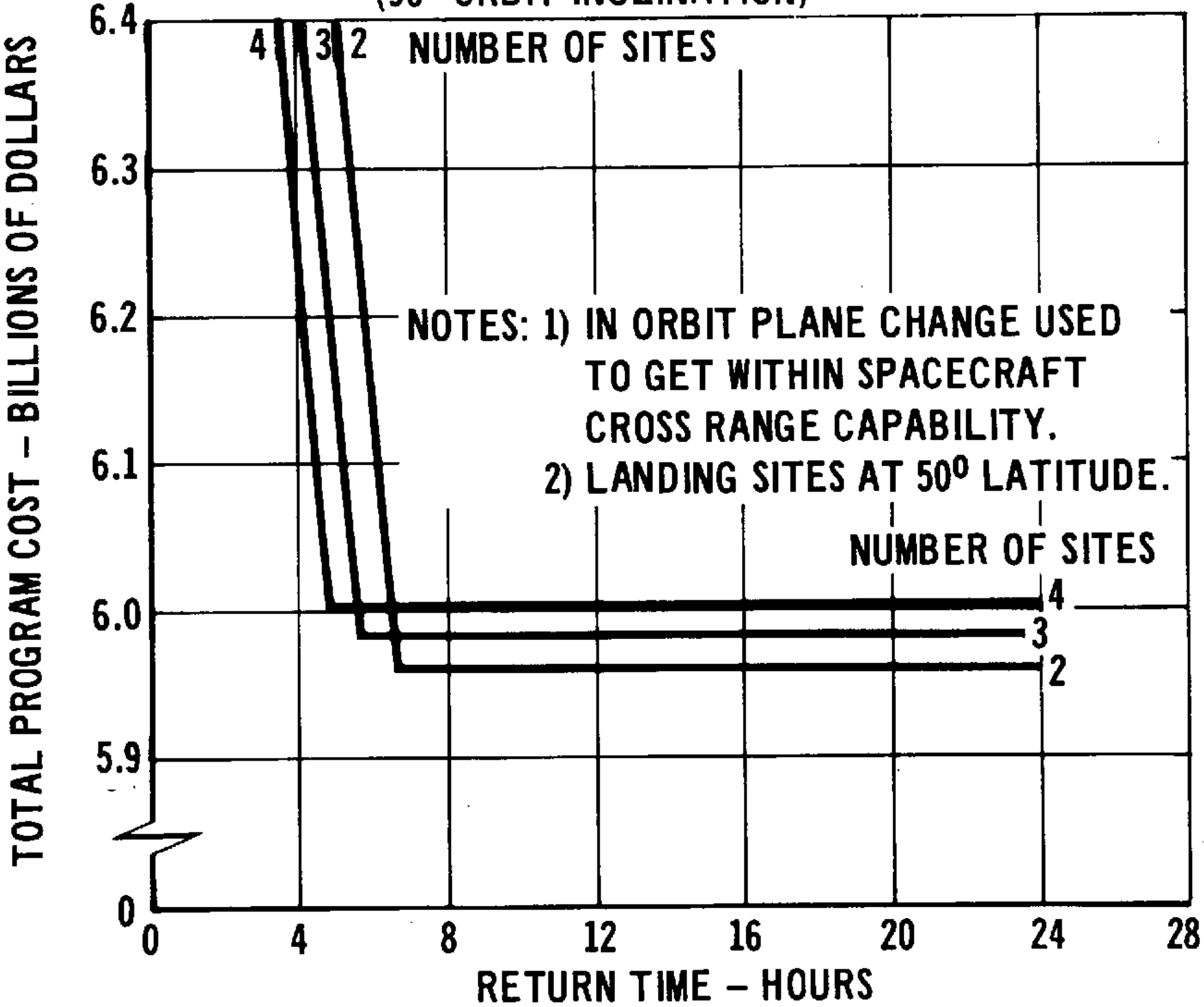
IIB COST VS. RETURN TIME AND NUMBER OF SITES

(90° Orbit Inclination)

The basic total program cost is shifted higher than for the 50° or 70° orbit inclinations because of the launch vehicles costs. Note that the addition of one site decreases the minimum return time by about 1 hour and saves about $250 million over the use of propulsion for a phasing maneuver.

COST VS. RETURN TIME AND NUMBER OF SITES

(IIB SPACECRAFT – MOD LIFTING)
(90^0 ORBIT INCLINATION)

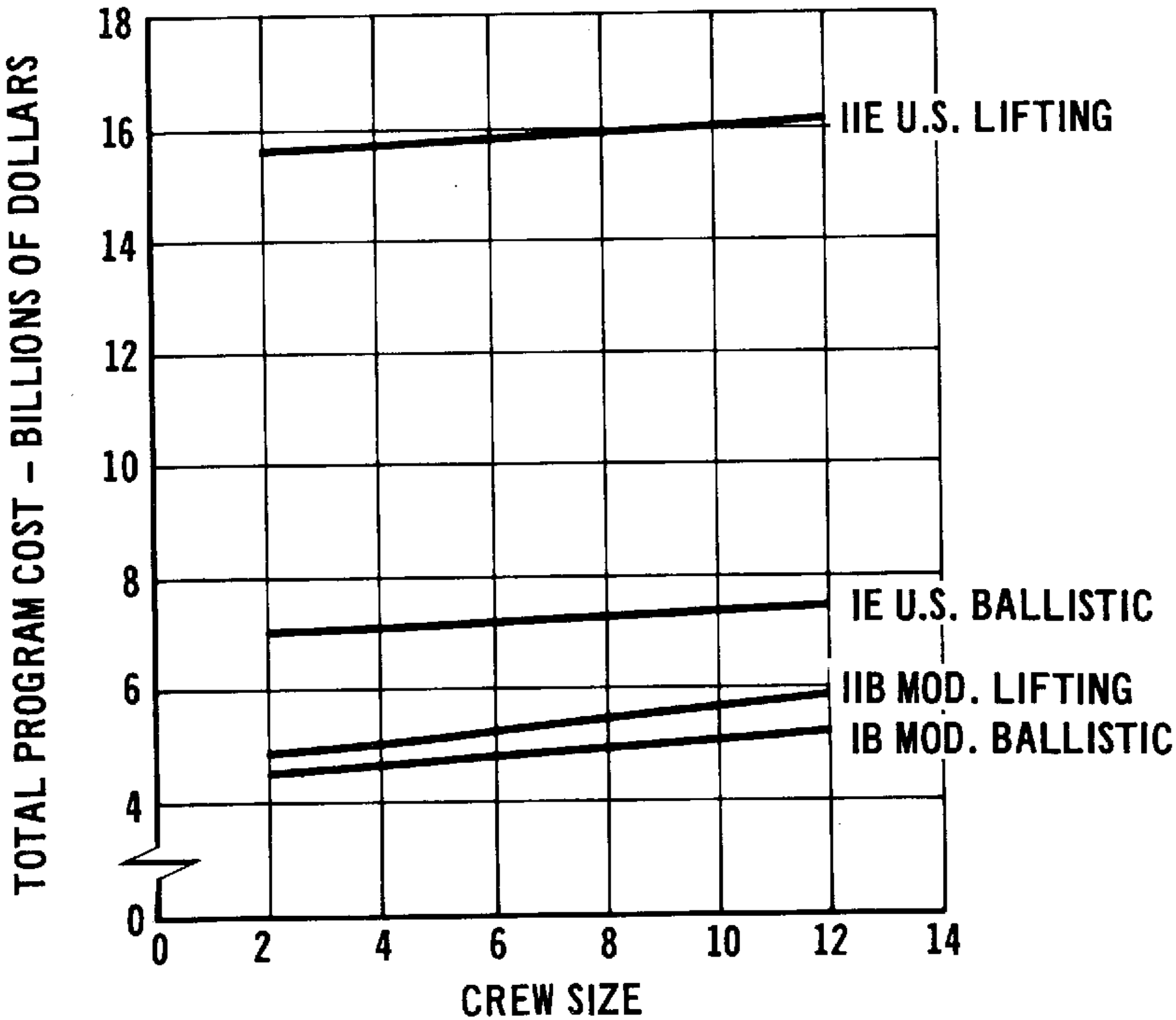


OCPDM–261

COST VARIATION WITH CREW SIZE

The total program cost varies by $750 million to about $1 billion as crew size varies from 2 to 12. The modular lifting body is most sensitive because the vehicle size changes the most.

COST VARIATION WITH CREW SIZE



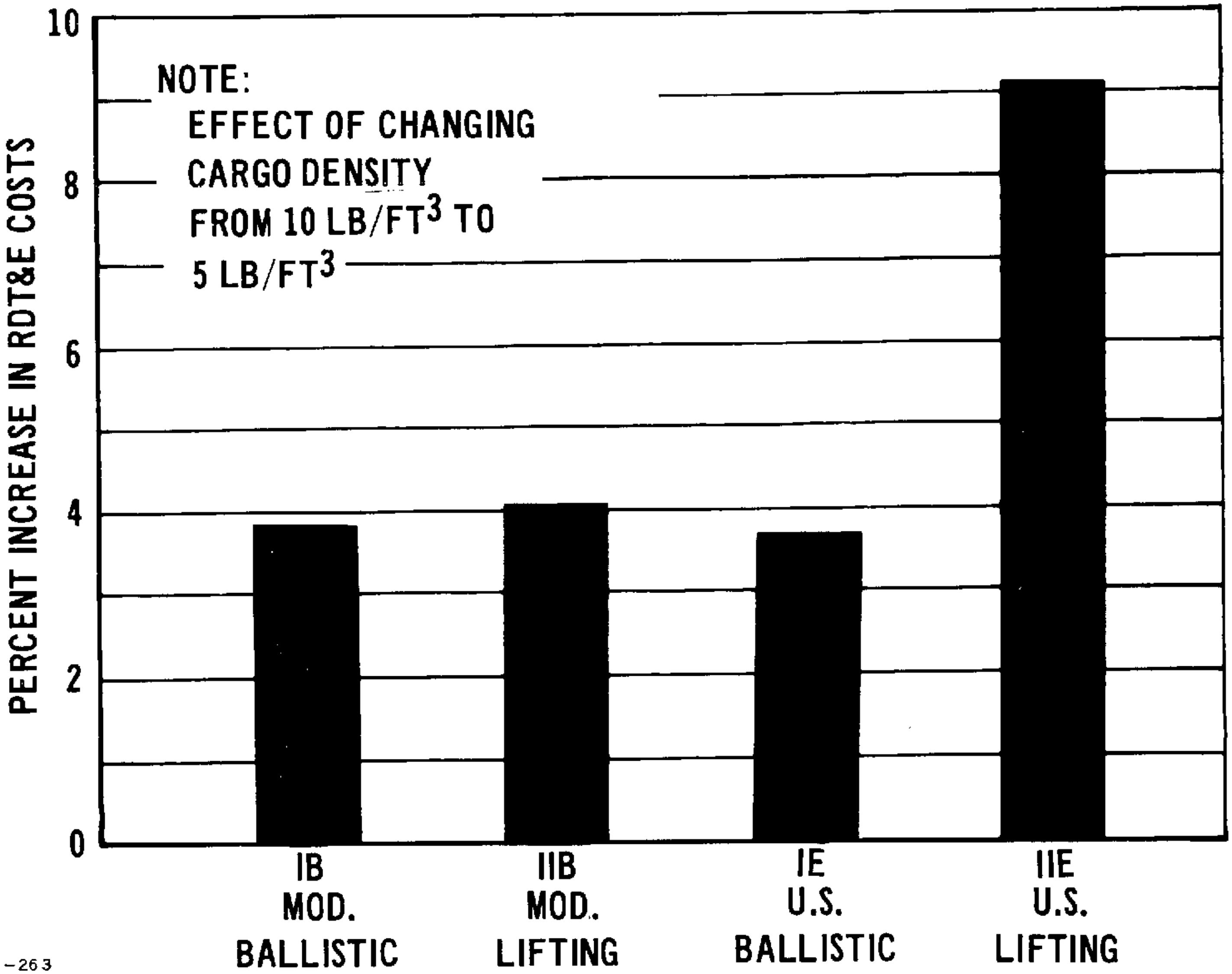
OCPDM-262

EFFECT OF DENSITY ON RDT&E COST

(Density is Reduced from 10 to 5 Pounds Per Cubic Foot)

The average cargo density was assumed to be 10 lbs/ft^3 for all the baseline programs. Decreasing the density to 5 lbs/ft^3 only increases the mission module for the modular vehicles and shows about a four percent increase in the RDT&E costs. The ballistic reusable upper stage (IE) cost is not as sensitive to increased volume requirements as the lifting body, (IIE), because of the better volumetric efficiency of the ballistic.

EFFECT OF CARGO DENSITY ON RDT&E COST



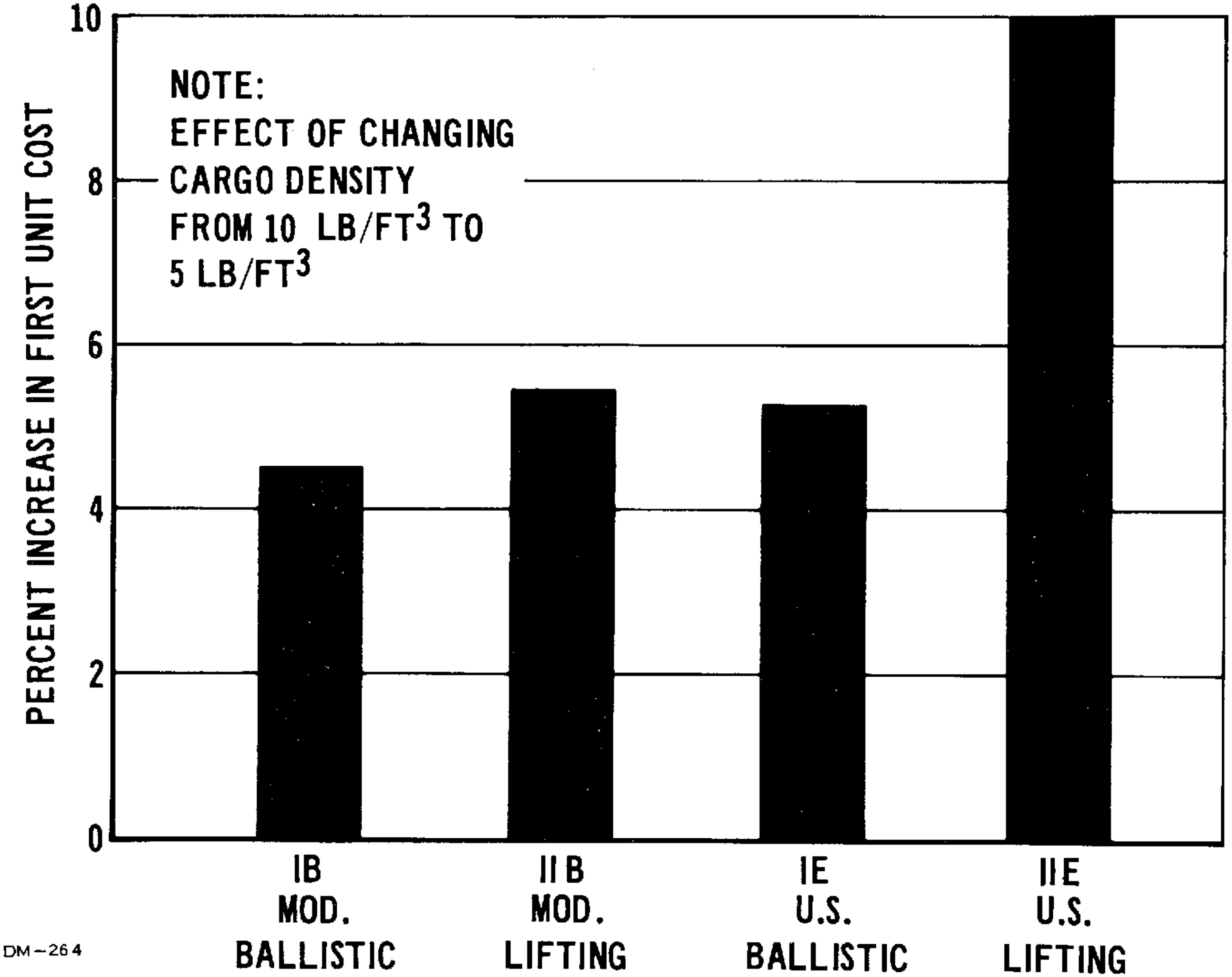
OCPDM-263

EFFECT OF DENSITY ON FIRST UNIT COST

(Density is reduced from 10 to 5 Pounds Per Cubic Foot)

The spacecraft first unit costs exhibit trends similar to those of the RDT&E phase for the same reasons.

EFFECT OF CARGO DENSITY ON FIRST UNIT COST



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